

The Future of Hard and Electromagnetic Probes at the SPS

Hard Probes 2004

Ericeira/Portugal November 4 – 10, 2004

- **Villars 2004** **Official CERN Workshop**
- **Physics** **Photons**
 Lepton Pairs
 Open Charm
 Charmonia
 (Jets)
- **Boundary Conditions** **SPS**
 FAIR, RHIC, LHC
- **Conclusions** **The CERN View**
 My View



Agenda - Villars meeting 22-28 September 2004

Date/Time: from
Wednesday 22 September 2004
(09:00) to
Tuesday 28 September 2004
(14:00)

Location: Villars, Vaud, Switzerland

Chairperson: J.B. Dainton

Material:  documents

Wednesday 22 September 2004 09:00->19:00	<u>Wednesday 22 September</u>	
Wednesday 22 September 2004 09:00->09:45	<u>Opening Session</u>	<u>John B. Dainton</u>
Wednesday 22 September 2004 09:45->16:00	<u>CERN accelerators, performance and outlook</u>	<u>John B. Dainton</u>
Wednesday 22 September 2004 16:30->18:45	<u>Heavy ions - SESSION 1</u>	<u>Louis Kluberg</u>
Thursday 23 September 2004 09:00->19:20	<u>Thursday, 23 September</u>	
Thursday 23 September 2004 09:00->12:15	<u>Heavy ions - Session 2</u>	<u>Louis Kluberg</u>
Thursday 23 September 2004 14:00->19:30	<u>Neutrinos - Session 1</u>	<u>David L. Wark</u>
Friday 24 September 2004 09:00->22:00	<u>Friday 24 September</u>	
Friday 24 September 2004 09:00->12:15	<u>Neutrinos - Session 2</u>	<u>David L. Wark</u>
Friday 24 September 2004 14:00->22:00	<u>Soft and hard hadrons - Session 1</u>	<u>Uta Stoesslein</u>
Saturday 25 September 2004 09:00->12:00	<u>Soft and hard hadrons - Session 2</u>	<u>Uta Stoesslein</u>
Saturday 25 September 2004 14:00->19:20	<u>Anti-protons - Session 1</u>	<u>Helena Bialkowska</u>
Sunday 26 September 2004 09:00->19:00	<u>Sunday 26 September</u>	
Sunday 26 September 2004 09:00->12:20	<u>Anti-protons - Session 2</u>	<u>Helena Bialkowska</u>
Sunday 26 September 2004 14:00->19:30	<u>Heavy flavour - Session 1</u>	<u>Gautier Hamel de Monchenault</u>
Monday 27 September 2004 09:00->17:15	<u>Monday 27 September</u>	
Monday 27 September 2004 09:00->12:00	<u>Heavy flavour - Session 2</u>	<u>Gautier Hamel de Monchenault</u>
Monday 27 September 2004 13:30->16:50	<u>Other topics</u>	<u>John B. Dainton</u>
Monday 27 September 2004 16:50->19:30	<u>Meeting conclusions -</u>	<u>John B. Dainton</u>

Heavy ions - SESSION 1 (16:30->18:45)

Chairperson: Louis Kluberg

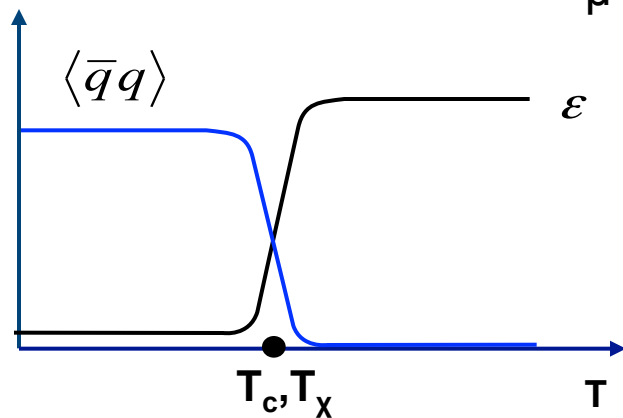
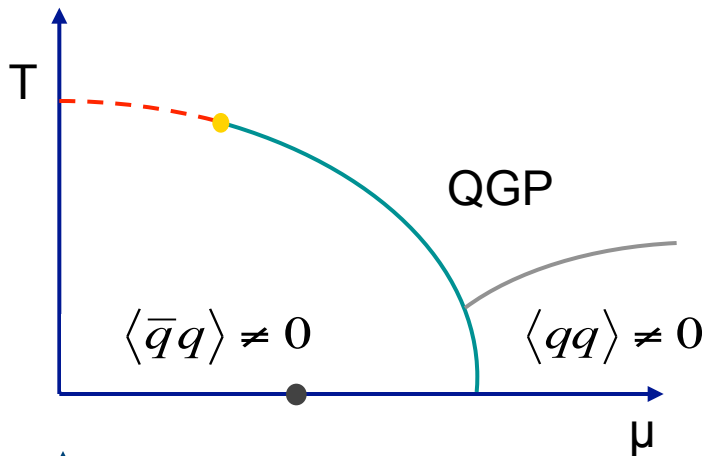
- 16:30 Experimental overview (1h00') ( [transparencies](#)) Itzhak Tserruya
- 17:30 Discussion (15')
- 17:45 Theoretical overview (1h00') ( [transparencies](#)) Bernd Mueller
- 18:45 Discussion (15')

Heavy ions - Session 2 (09:00->12:15)

Chairperson: Louis Kluberg

- 09:00 NA49 prime - ions programme (35') ( [document](#)  [transparencies](#)) Marek Gazdzicki
- 09:35 Discussion (10')
- 09:45 NA49 prime, astroparticle physics programme (10') ( [transparencies](#)) Andreas Haungs
- 09:55 Discussion (05')
- 10:00 NA60:Study of dimuon and heavy-flavour production in
proton-nucleus and heavy-ion collisions (45') ( [document](#)  [transparencies](#)) Carlos Lourenco
- 10:45 Discussion (15')
- 11:00 Critical behaviour in QCD (30') ( [transparencies](#)) Helmut Satz
- 11:30 Availability of ions at the SPS (05') ( [transparencies](#)) Jean-Pierre Riunaud

What did we want to learn from em and $c\bar{c}$ probes?

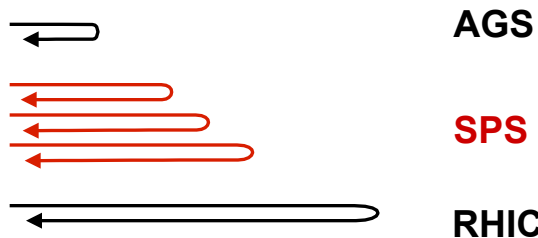


Goals

- existence and properties of deconfined state
- nature and parameters of deconfinement transition
new: critical point
- existence and parameters of chiral transition

Tools

- measure ε , measure $T \rightarrow$ get v from $\varepsilon = vT^4$
($T < T_c$, $T > T_c$)
- measure ρ meson behaviour $\rightarrow$ disappearance for $T > T_x$
($T < T_x$, $T > T_x$)
- measure J/ψ suppression $\rightarrow$ disappearance for $T > T_c$
($T < T_c$, $T > T_c$)



Parameters

- CM energy $\sqrt{s}$ $\rightarrow$ vary ε, T, μ
- nuclear size A $\rightarrow$ vary $V + \dots$
- impact parameter b $\rightarrow$ vary $\varepsilon, T, \mu, V + \dots$

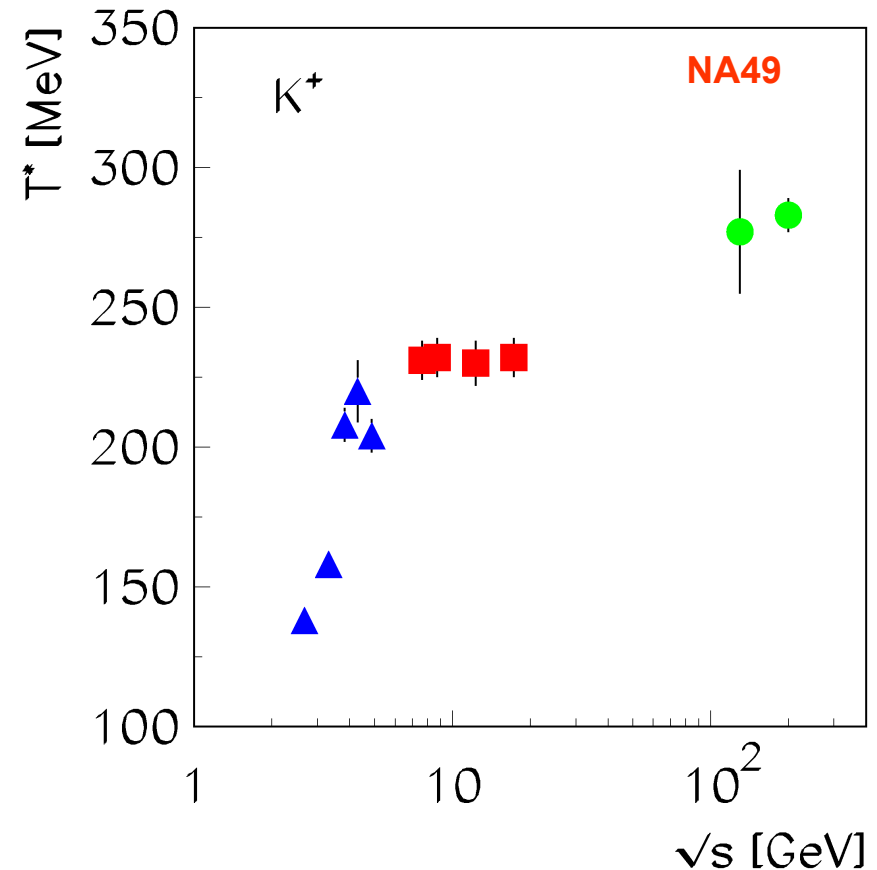
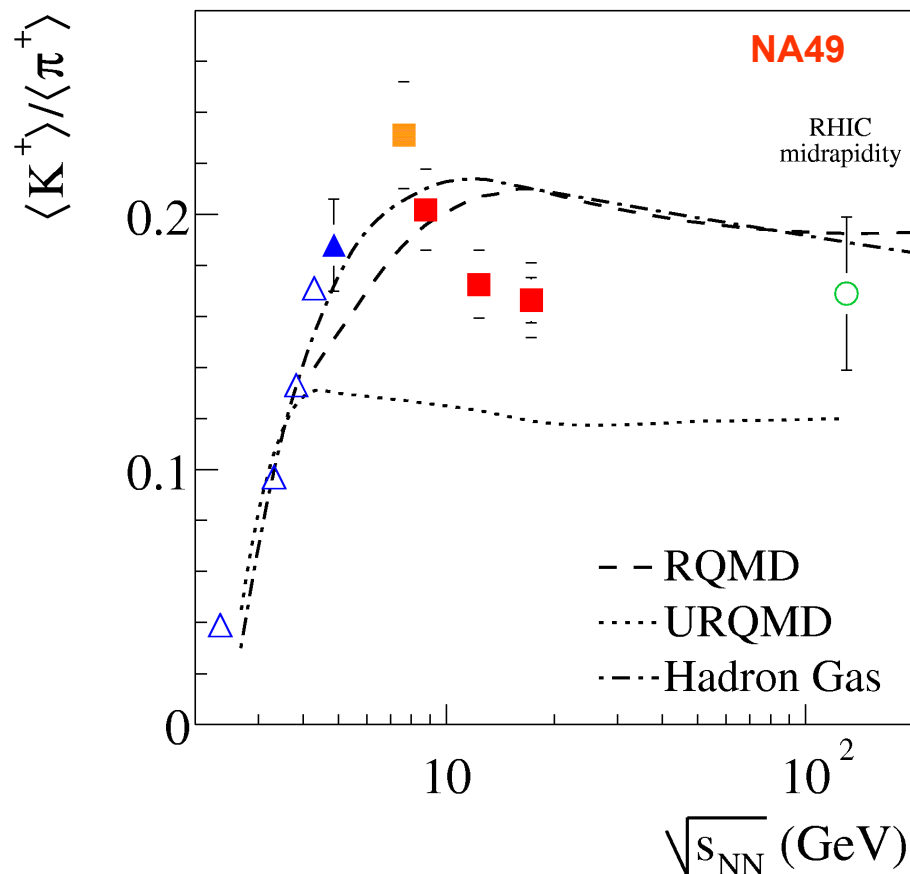
SPS unique in terms of excitation functions

Possible Evidence for the Critical Point

Importance of **excitation functions in narrow steps**:

so far illustrated only for soft probes: particle yields, v_2 , HBT....

Most interesting result: $K^+/\pi^+, T_{K^+}$; first “discontinuity”?



What did we achieve?

Probe	Range	Full energy 158 AGeV/c		Excitation function 80/40/30/20 AGeV/c	
		AA PbPb	Comparison pp,pA	AA PbPb	Comparison pp,pA
Photons	$p_t < 0.1$ (GeV/c)	-	+	-	-
	$0.1 < p_T < 1.5$	-	-	-	-
	$p_T > 1.5$	(+)	-	-	-
Lepton Pairs	$m < 0.2$ (GeV/c ²)	-	(+)	-	-
	$0.2 < m < 1.2$	(+)	+	(+)	-
	$m > 1.2$	(+)	(+)	-	-
Open charm	Identif. comb. l^+l^-	-	-	-	-
	Identif. D-decays	-	(+)	-	-
Charmonia	$J/\psi, \psi'$	(+)	(+)	-	-

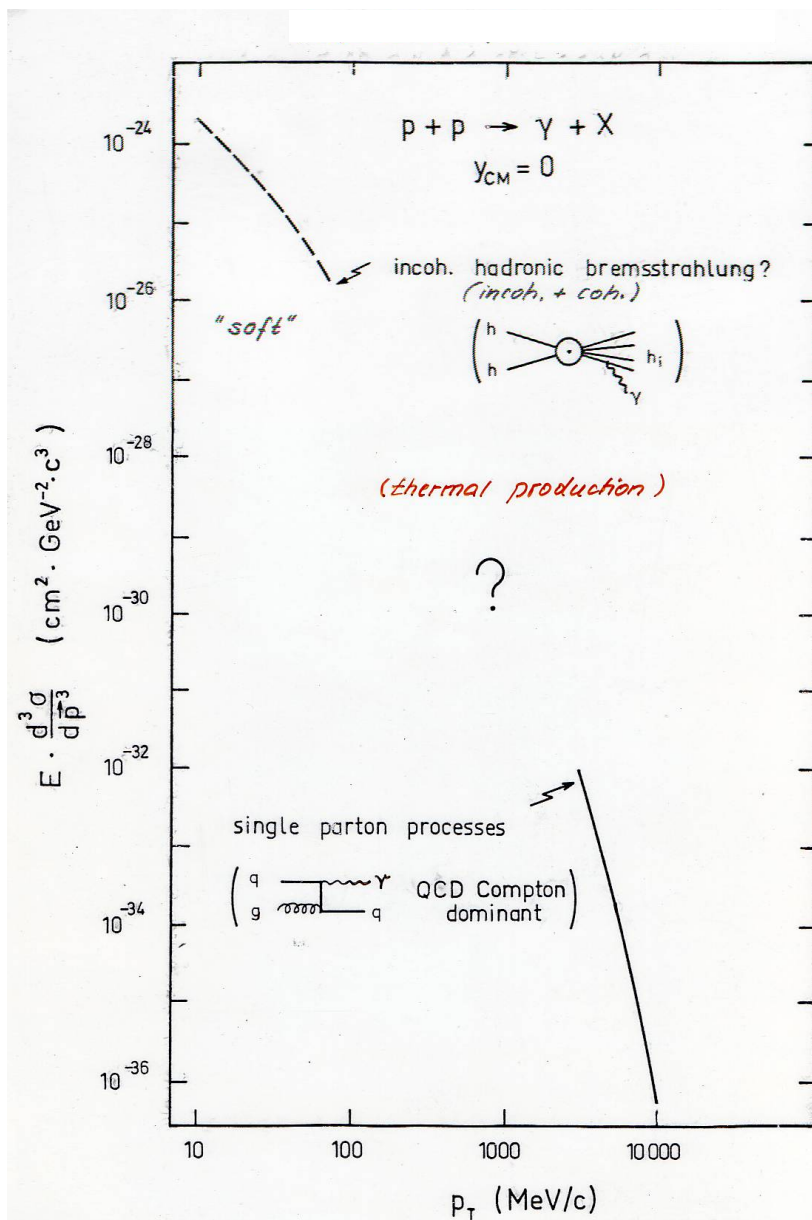
No usable temperature measurement yet

No solid proof of ρ change yet

No measurement of charm level yet

No clear understanding of J/ψ suppression yet

Dynamic range of photon measurements



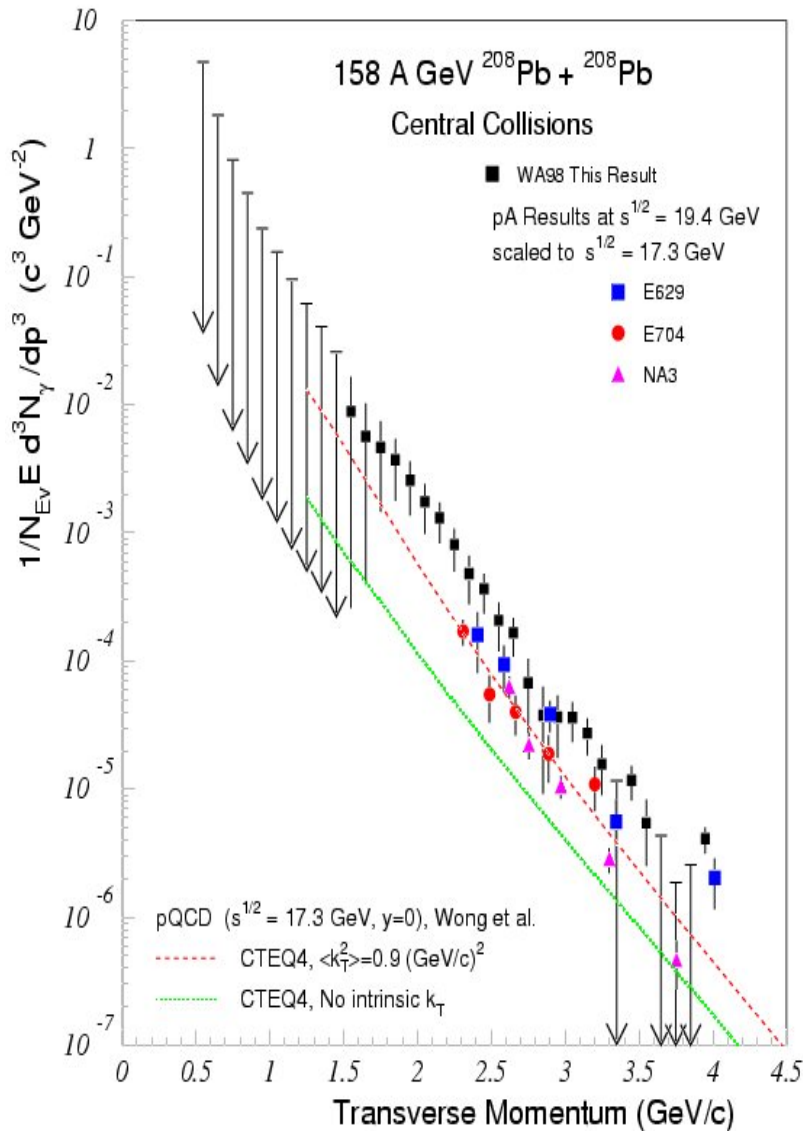
- Bremsstrahlung $0.001 < p_T < 0.1 \text{ (GeV/c)}$
- thermal radiation $0.1 < p_T < 5$
- hard parton processes $p_T > 3$

→ potential dynamic range $> 10^3$

compare to em radiation in astronomy today

→ radio, IR, visible, UV, X, γ

Photon reality in AA



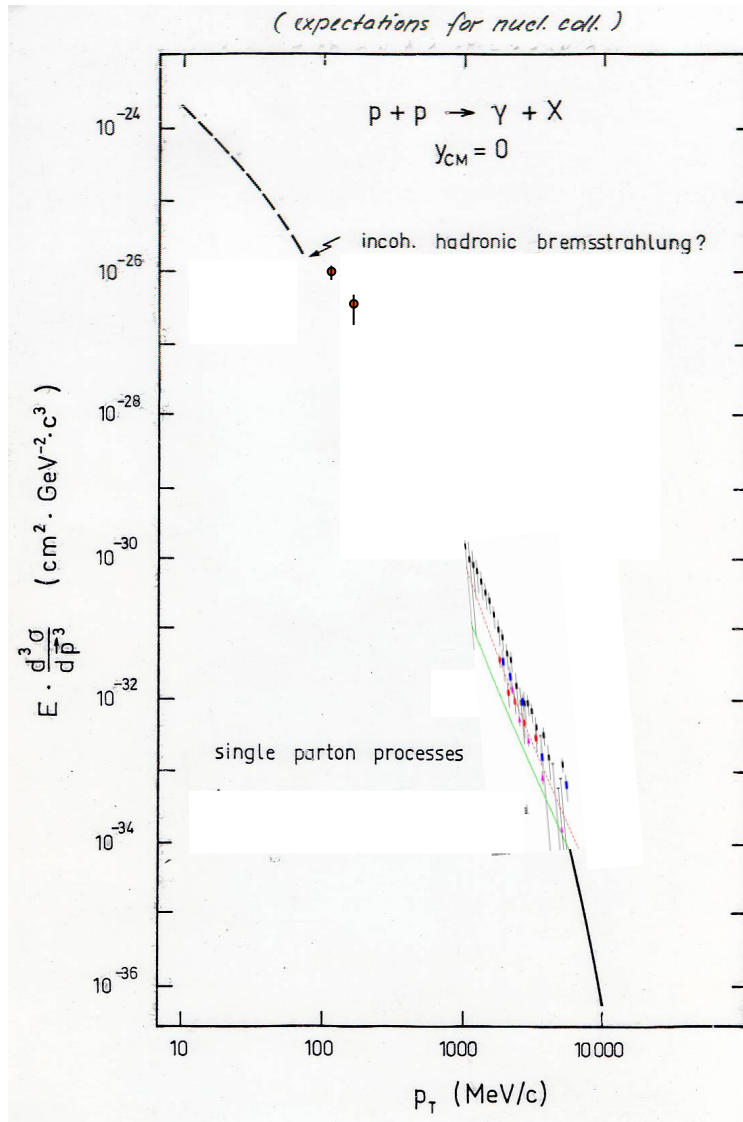
problems

- usable dynamic range < 2
- no pA comparison data
- model ambiguities

→ large ambiguities in extraction of T_i

- Gale (HP2004) 205 MeV
- Rapp and Shuryak (2000) 210 MeV
- Gale (HP2004) 270 MeV
- Srivastava (2001) 330 MeV

Dynamic range of photons and present reality



Usable dynamic range < 2

→ just the “visible light”
of astronomy

but now 2 points at lower p_T

Can we do better?

$p_T < 1.5 \text{ GeV/c}$:

precision instrumentation

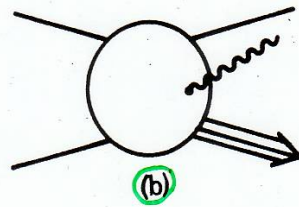
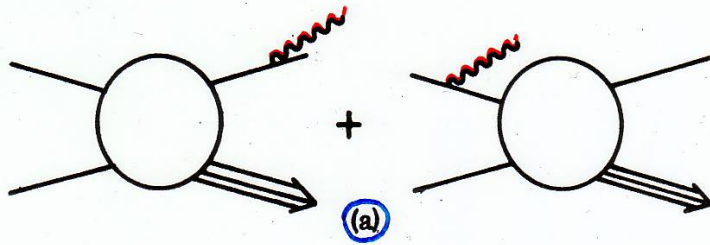
$p_T < 0.1 \text{ GeV/c}$:

definitely feasible

Soft Photon Bremsstrahlung

Low, Phys. Rev. 110 (1958) 974

$$\sigma_f = \underbrace{\frac{G_0}{k}}_{(a)} + G_1 + G_2 \cdot k + \dots$$



photons from
virtual particles

in the soft photon limit $k \rightarrow 0$

unique values for G_0 and G_1 ;
calculable from scattering amplitudes
without photon radiation

→ bremsstrahlung determined by "outer particle lines"

pp, pA

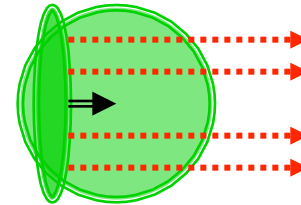
incoherent Bremsstrahlung:

hadrons radiate independently

"coherence":

hadrons radiate, not partons inside

AA



coherent Bremsstrahlung:

nuclei radiate, not hadrons inside

→ $\sigma \sim Z^2$! → collision dynamics

other sources of soft photons

"(first) window to chiral symmetry?"

C.Gale, HP2004

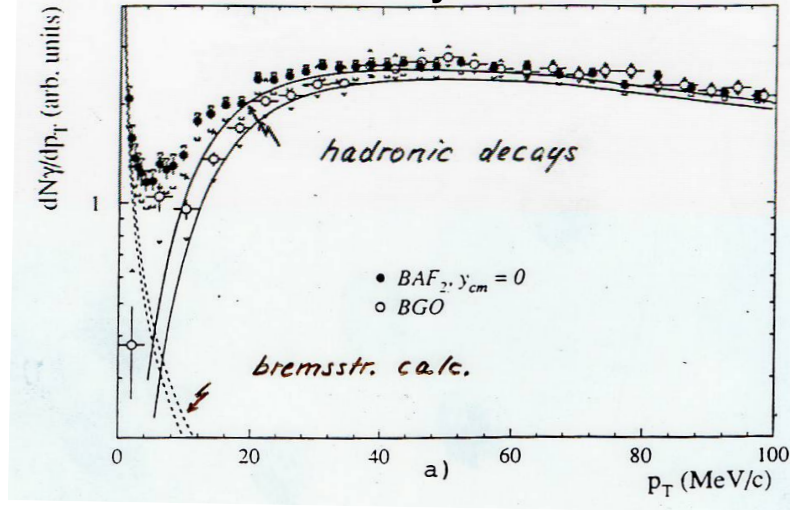
Soft Photon Bremsstrahlung

pBe at 450 GeV/c

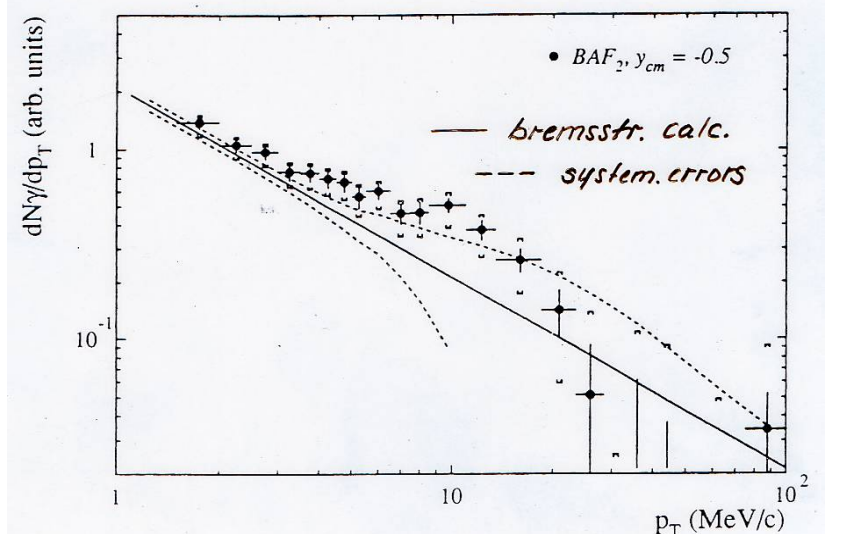
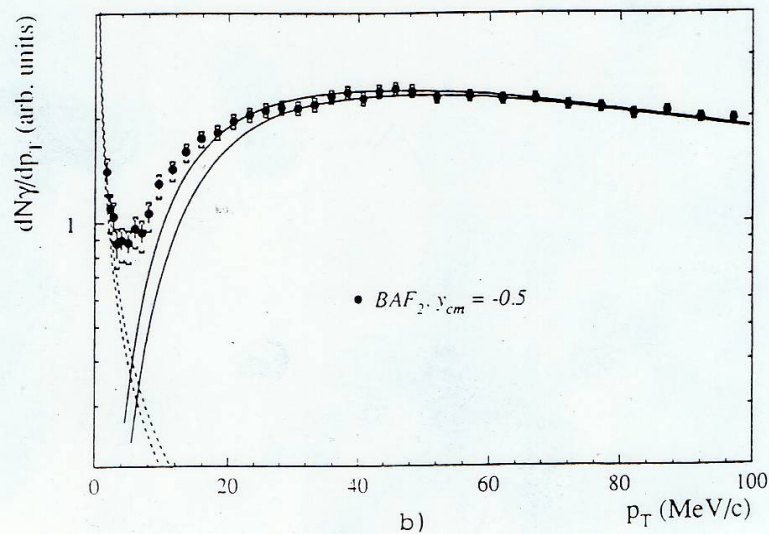
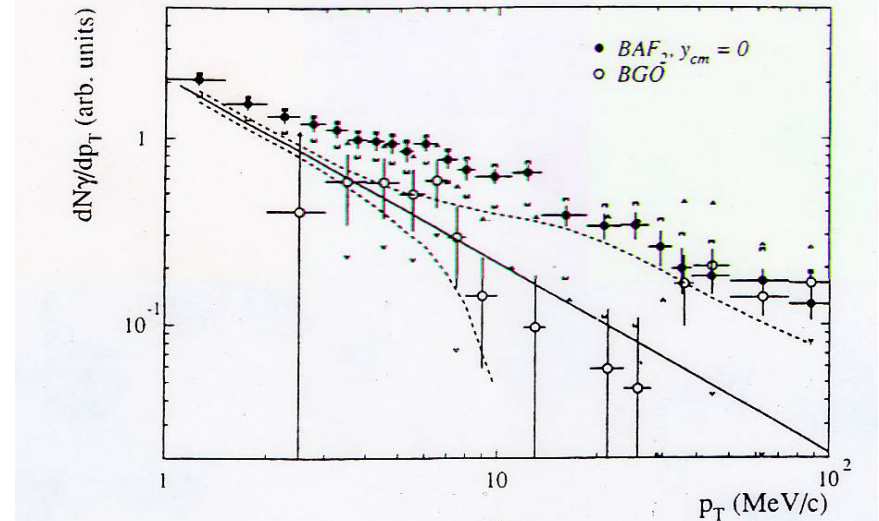
SOPHY/BACY within HELIOS/NA34

Anthos et al., Z.Phys. C59 (1993) 547

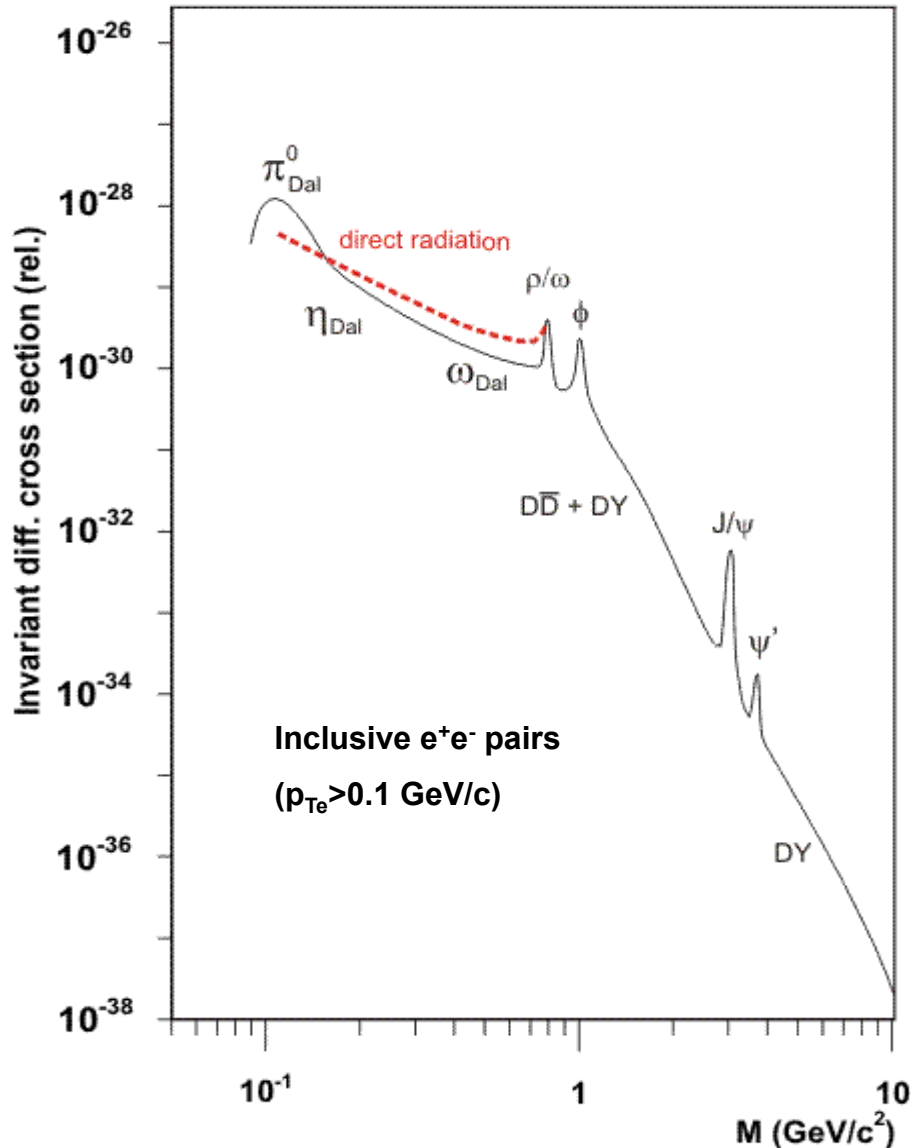
Raw data + Decay Simulations



Net data



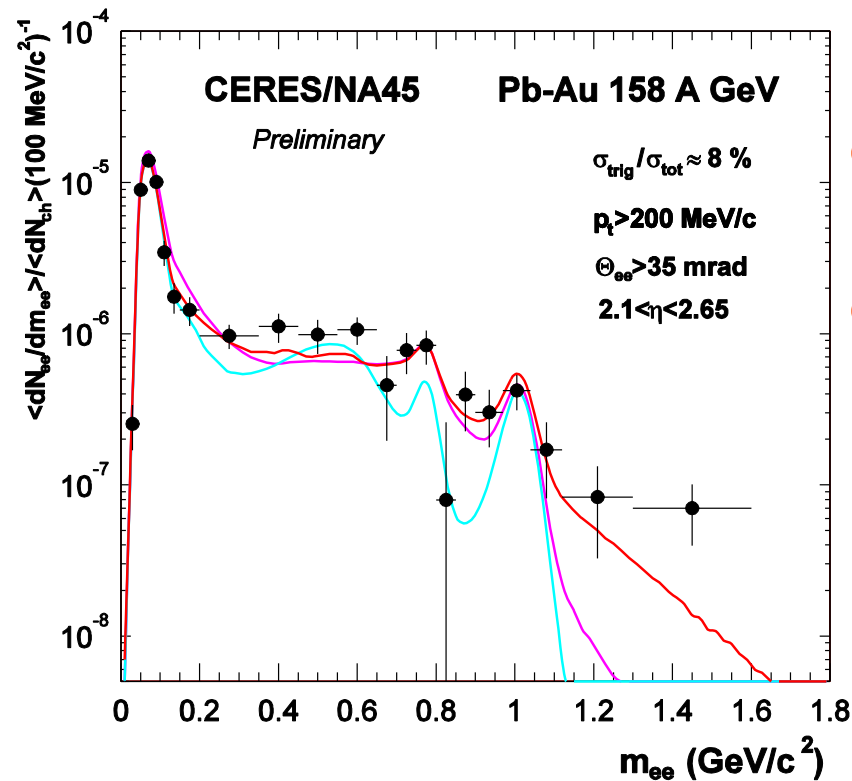
Dynamic range of lepton pair measurements



- Bremsstrahlung $0.001 < m < 0.1 \text{ GeV}/c^2$
(plot $m > 0.02$, but pp data!)
- thermal radiation $0.1 < m < 1.2$
(light vector meson spectral densities)
- thermal radiation $1.2 < m < 3$
(continuum regime)
- hard parton process (DY) $p_T > 1.2$
(dominant for $p_T > 3$)

→ potential dynamic range of $> 10^3$

Low Mass Electron Pairs/CERES



⊕ existence of strong excess above hadron decays

⊖ limited in statistics and resolution

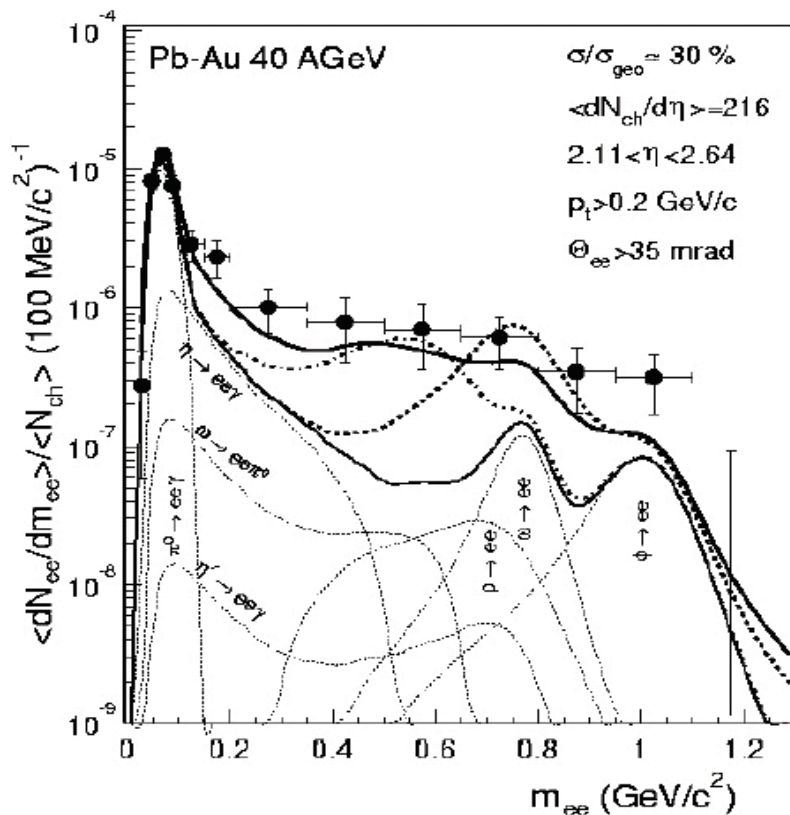
1995/96	(30%)	(2600) 220	7%
2000	(8%)	(2200) 160	4%

⊕ excess = rate * space-time volume * medium influence

⊖ mechanism open:

- disappearance of vacuum ρ ?
- ρ melting à la Brown-Rho scaling?
- ρ melting à la Rapp/Wambach?
- ☒ qq annihilation?

Low Mass Lepton Pairs/ CERES



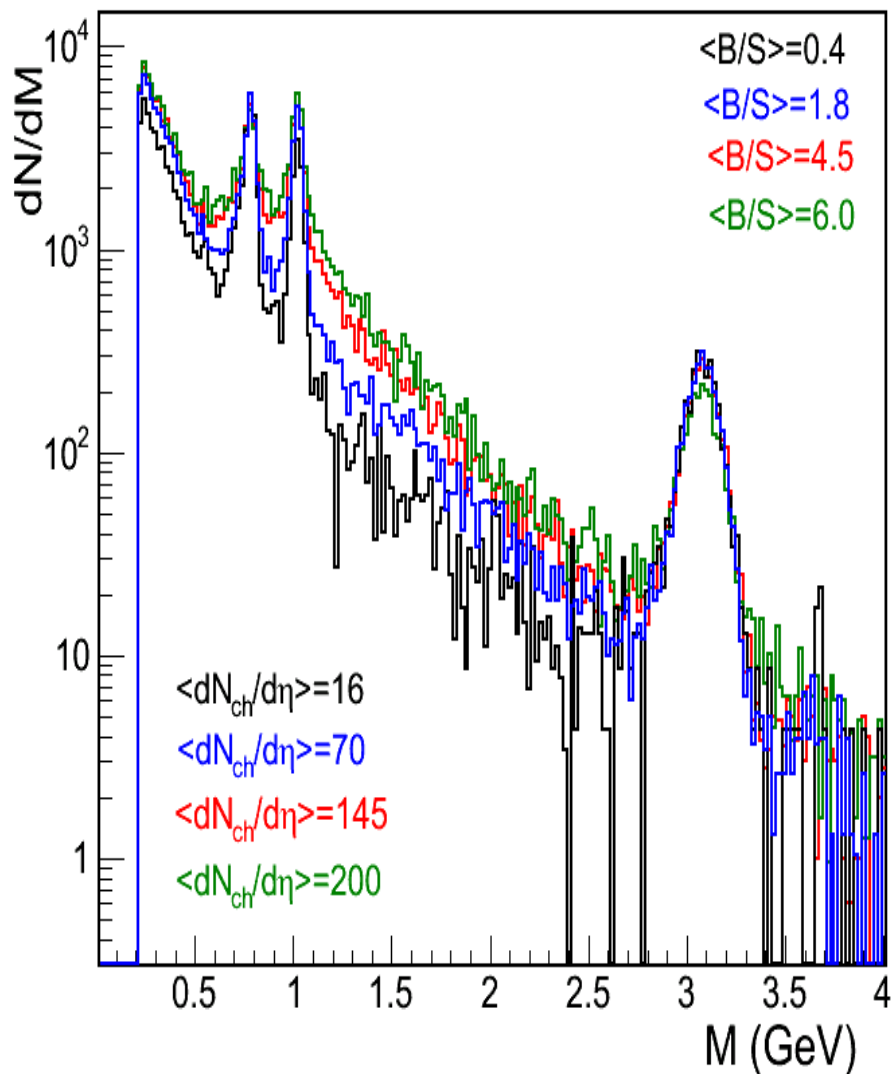
only example for a measurement
of an electromagnetic/hard probe
at a lower SPS energy!

statistics (180) 30 pairs

enhancement (40 AGeV) >
enhancement (160 AGeV)
→ baryons driving ρ melting?

→ precision measurements of low mass lepton
pairs at lower SPS energies absolutely vital
(will never come from RHIC)

Low Mass Lepton Pairs/NA60

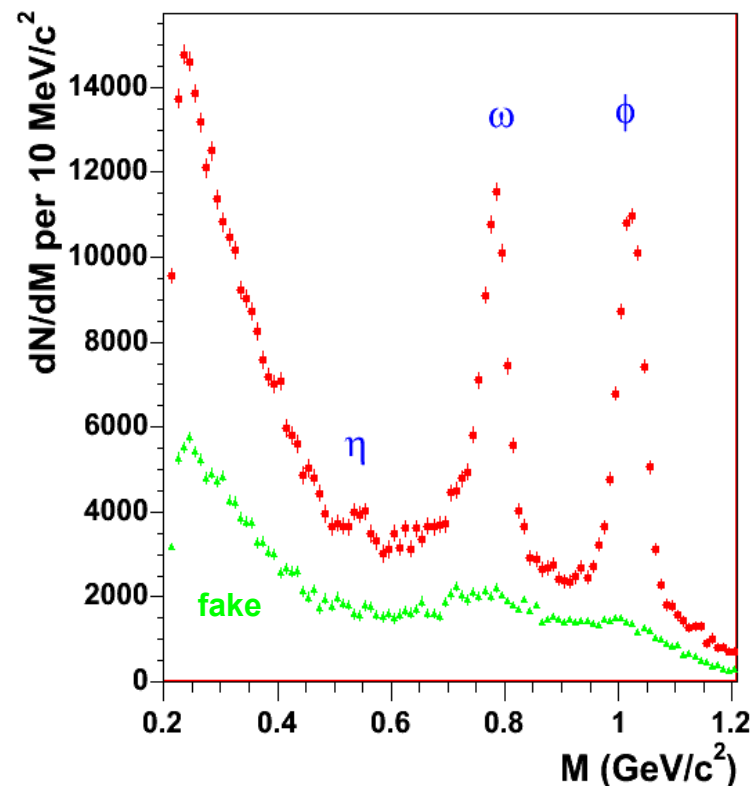


sample size (35%) 370000

final sample $10^6 \rightarrow 200000$

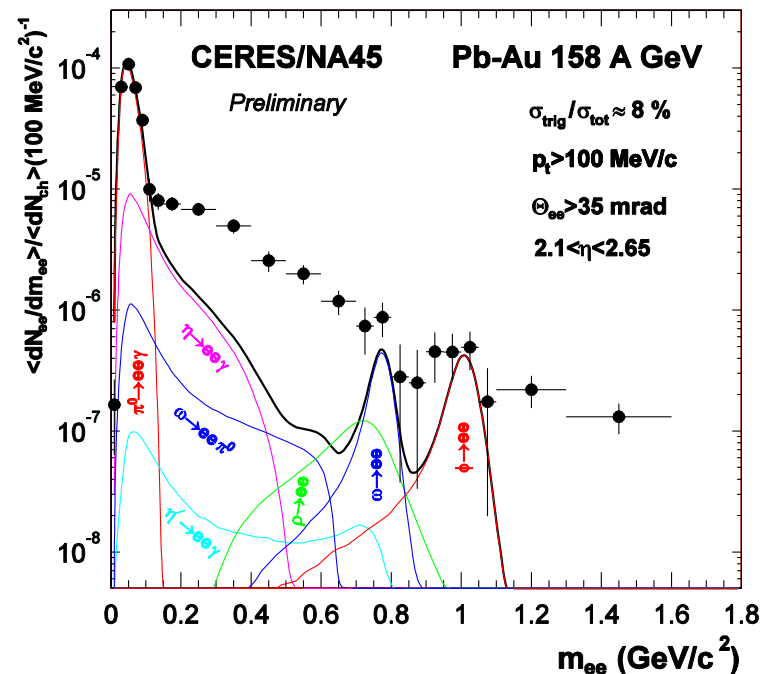
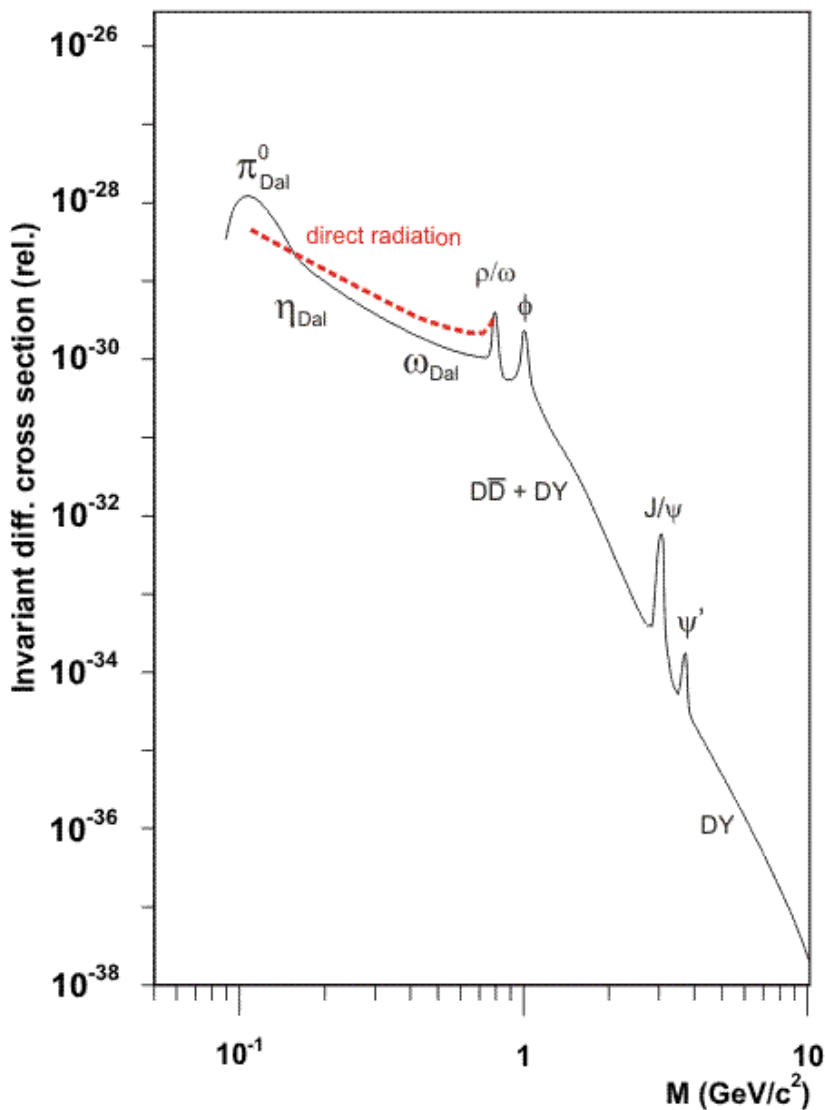
mass resolution

at the $\phi(1.02\text{GeV})$ 23 MeV



Statistics, mass resolution and multiplicity dependence should bring a major advance in the understanding of low mass lepton pair production

Soft Electron Pairs



cuts $p_T < 50$, $m_T < 100$

→ explore π^0 Dalitz region

(absolute normalization required)

S/B ratio may stay > 1.2

Soft electron pairs have analogous information to soft photons

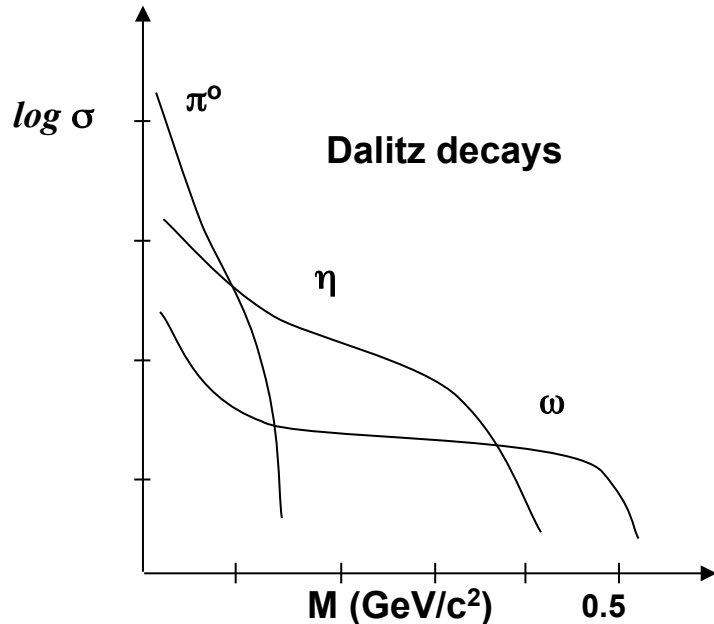
“Quasi Real” Photons?

basic idea: use lepton pairs with small mass m

select $p_T \gg m$

→ virtual photons close to the pole

problem:



relative to $\pi^0, \eta \rightarrow \gamma\gamma$

Dalitz suppressed by factor α

relative to γ

$\gamma^* \rightarrow l^+ l^-$ suppressed by factor α

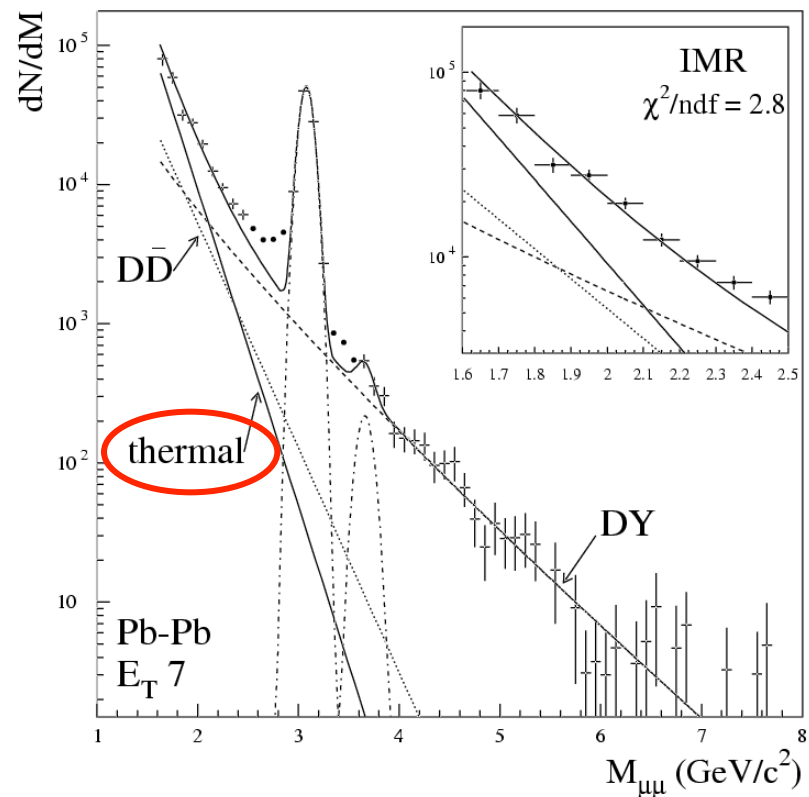
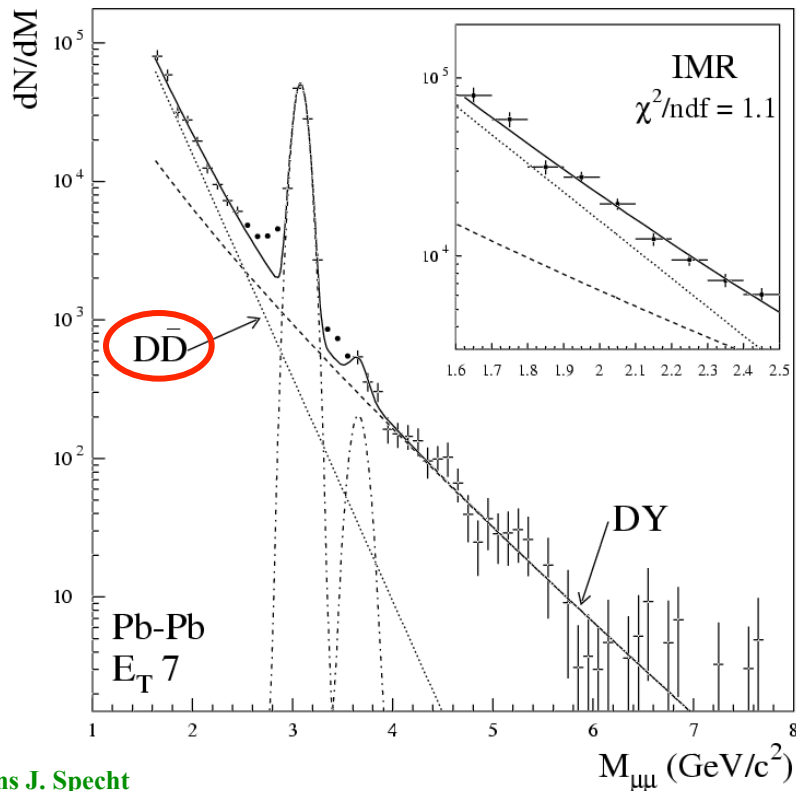
→ probably no net gain

Intermediate Mass Open Pairs/NA50

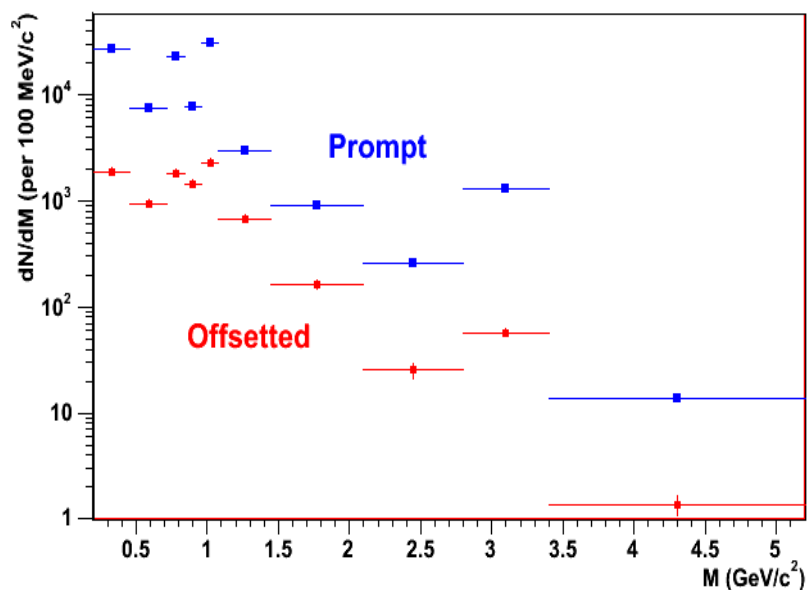
Charm enhancement or thermal dimuons ?

The intermediate mass dimuon yields can be reproduced :

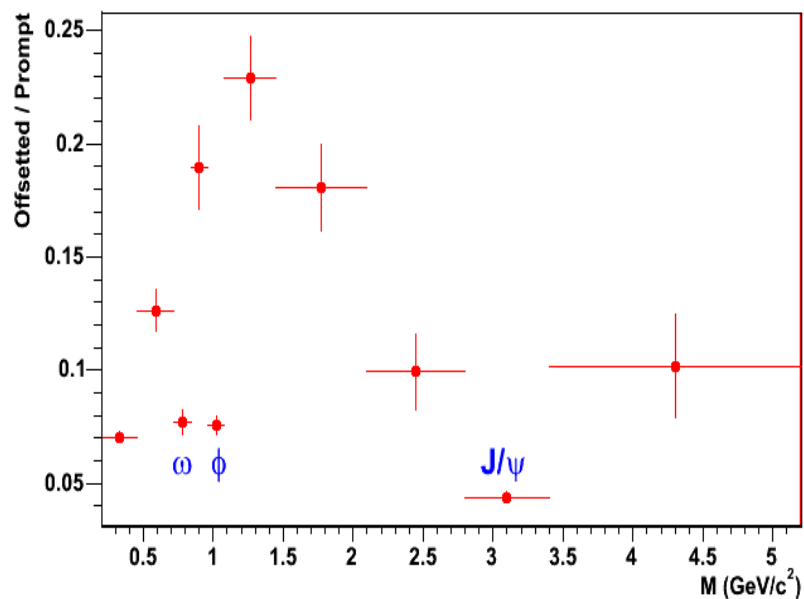
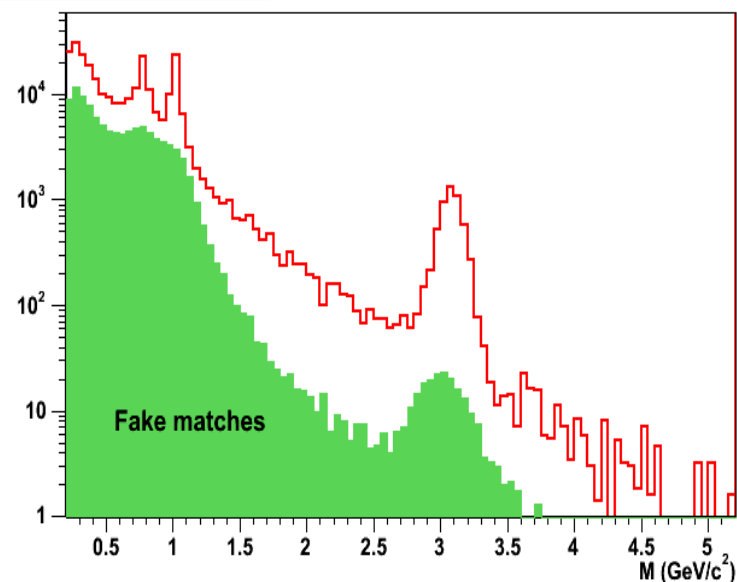
- by scaling up the charm contribution by up to a factor of 3 (!)
- or by adding thermal radiation to the DY and open charm



Evidence for Open Charm/NA60



sigdata $\pm$ b1 Δ vs Mass



Significant offset yield in the mass region $1.2 < m < 3 \text{ GeV}/c^2$, but also between the ω and the ϕ and below the ω

D-decays

RHIC: at least in d+Au:
several D-decays (2 and > 2-body) identified

SPS: great history in pp
(the experimental revolution of Si-strip detectors)

no transfer of that culture to the initial AA program

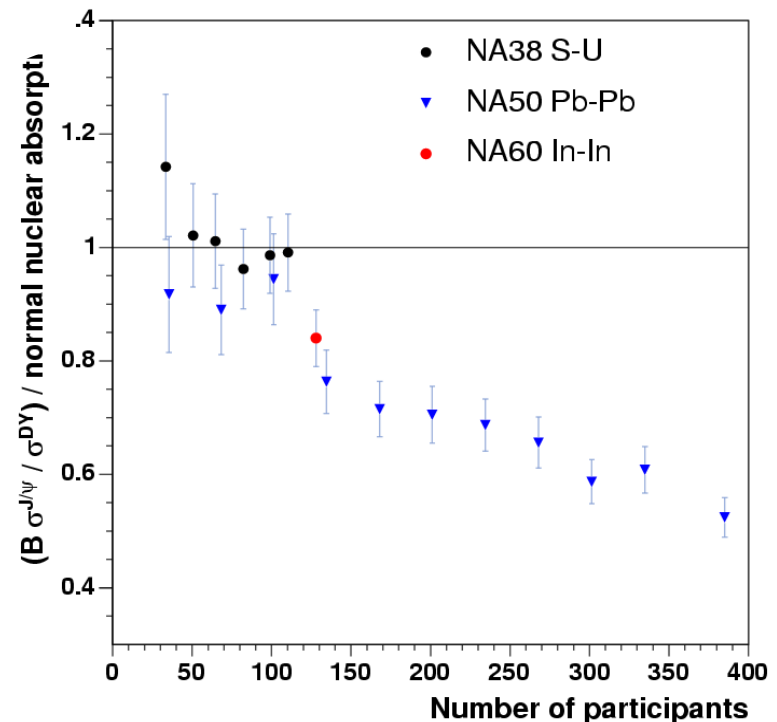
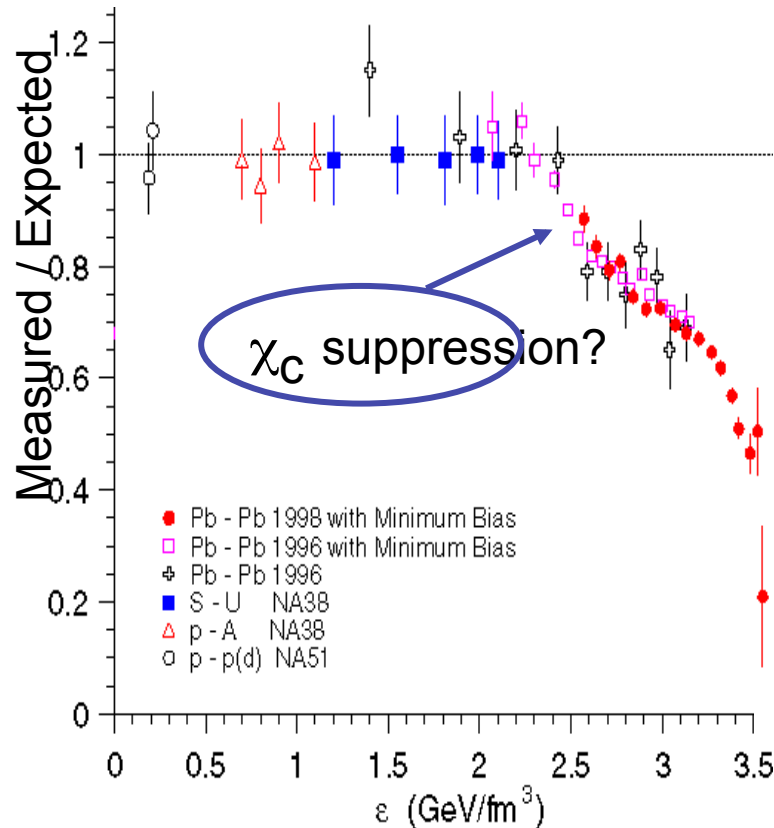
CERES ?

NA60 ?

A dedicated new effort ?

J/ψ suppression/NA50 +NA60

Anomalous J/ψ suppression: **evidence for deconfinement?**

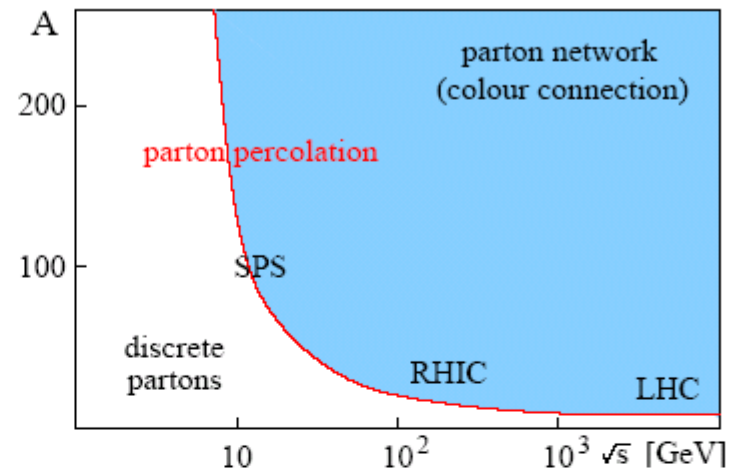


- Is the deconfined phase reached through a geometrical transition (percolation) or through a thermal transition (QGP) ?
- does the J/ψ melt through initial-state parton density (structure functions) or final state-parton density (QGP)?

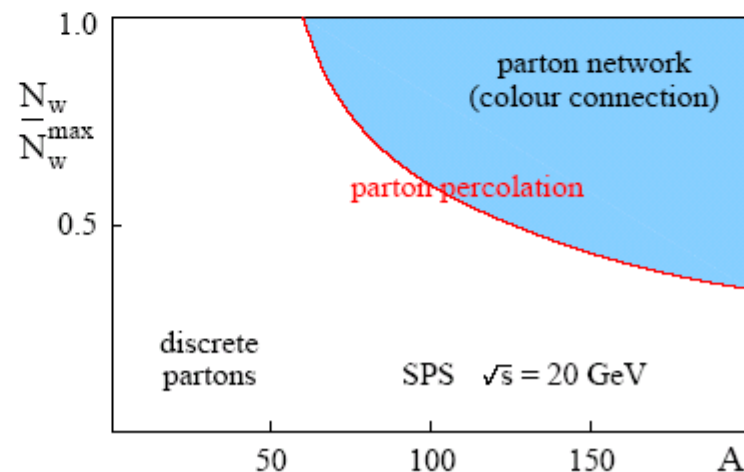
Percolation at SPS Energies/H.Satz

schematic:
central $A-A$ collisions
vs. A and $\sqrt{s}$

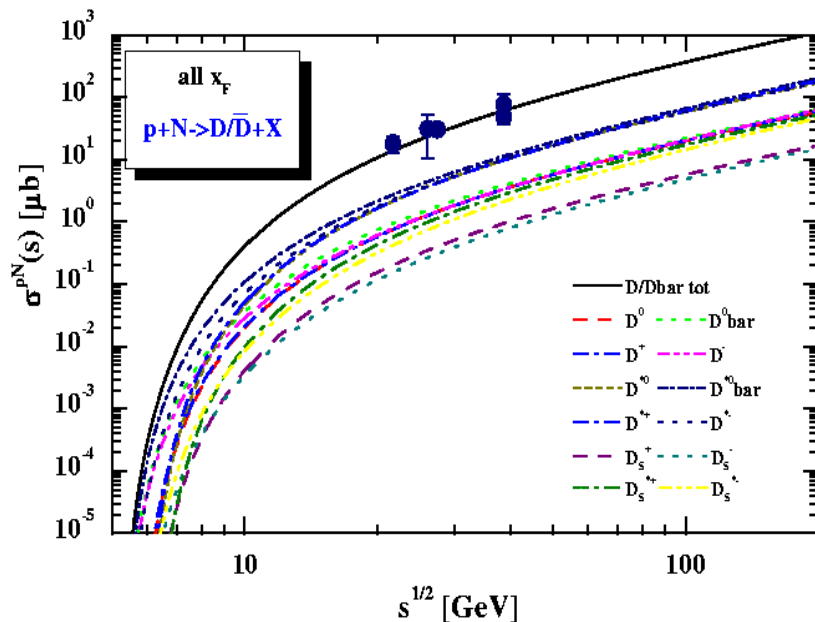
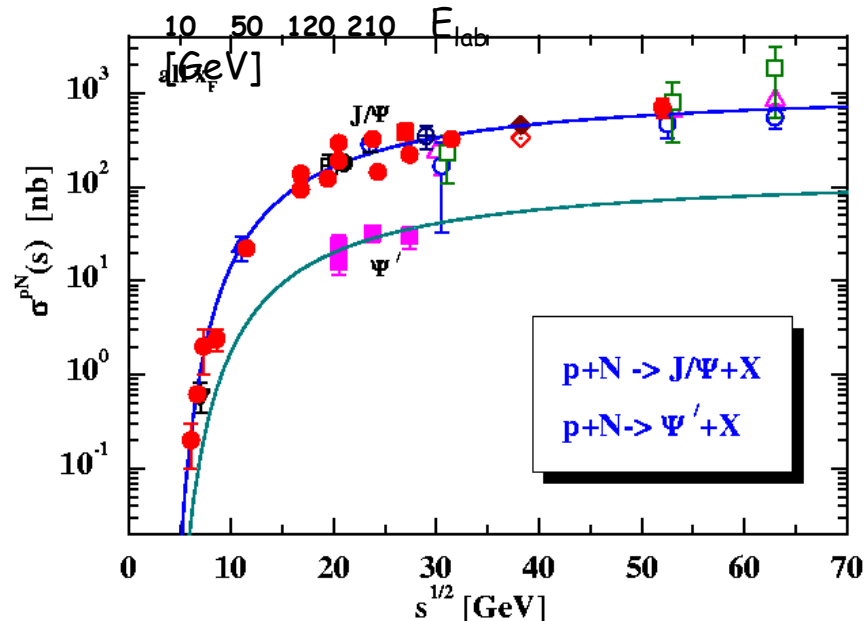
$\Rightarrow$ onset of percolation
best accessible at SPS



schematic:
 $Pb-Pb$ collisions
vs. centrality
SPS, $\sqrt{s} = 20$ GeV



Excitation Function of Charm and Charmonia Production



Can the physics of J/ψ , ψ' and open charm be done at lower energy than 158 AGeV?

energy (AGeV)	158	40	
σ_{rel}	1	0.08	0.08
$\langle y \rangle$	3.5	3.5	2.2
rel. loss	1	0.2	1
rel. total	1	0.016	0.08
J/ψ 's	100000	1600	8000

GSI quotation:

$10^5 J/\psi$ /week at 25 AGeV !

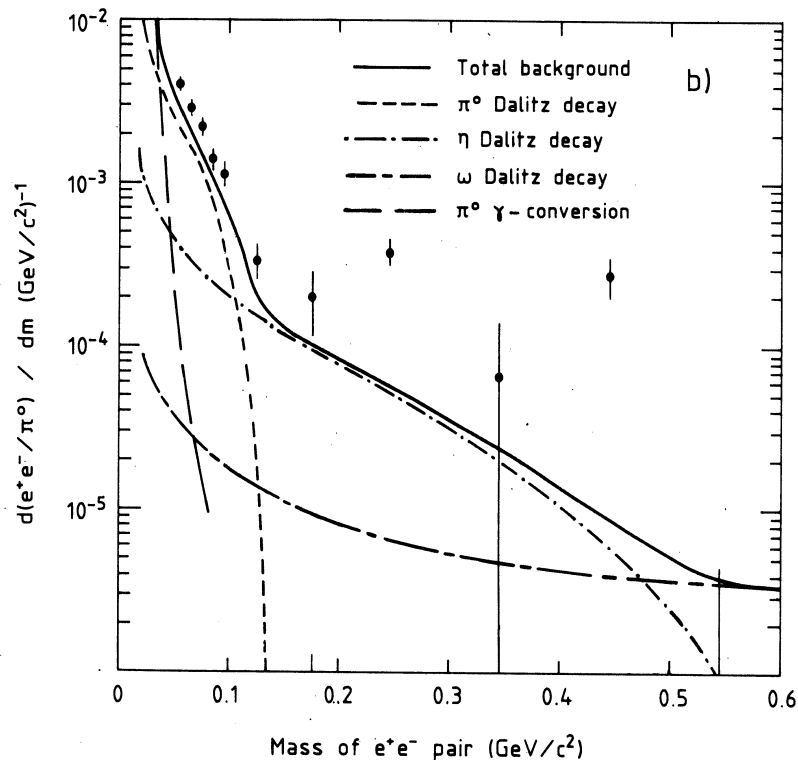
Luminosity

Luminosity, Luminosity, Luminosity!

Invariant mass spectra of e^+e^- pairs

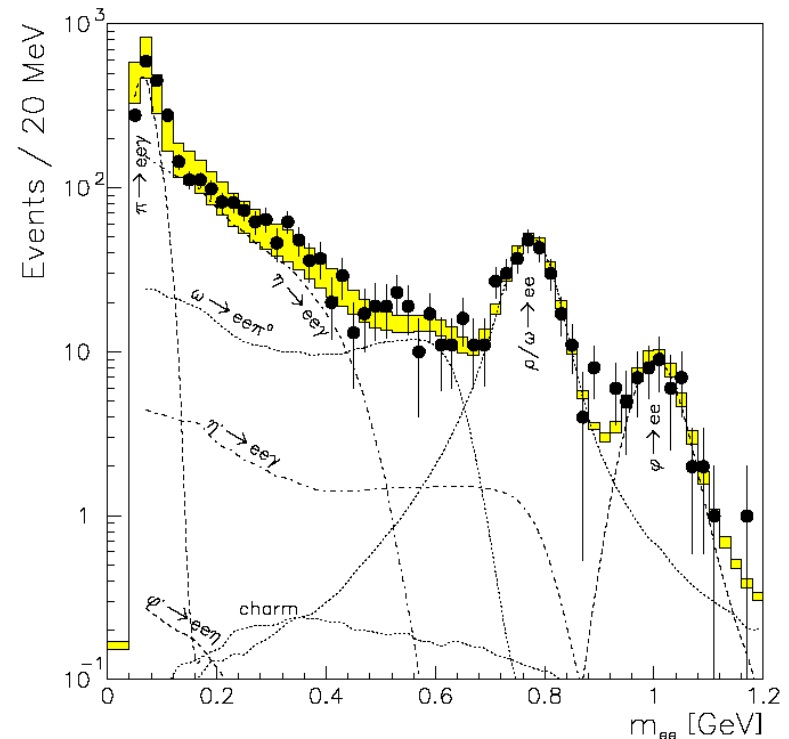
R807/ ISR

Phys.Lett.B (152) 411 (1985)



HELIOS N34/ SPS

Z.Phys.C 68 (1995) 47



Availability of Heavy Ions for SPS Fixed Target Physics

Until Nov. 2003, Heavy Ions for Fixed Target physics were produced via :

Ions source – Linac 3 - PS Booster – PS - SPS

Since then, the production of Lead Ions for LHC has started via :

(new) Ions source – Linac 3 - LEIR – PS - SPS

⇒ The previous Heavy Ions route via the PSB is not available anymore as synchronisation PSB/Linac3 has been disactivated and converted into a synchronisation LEIR/Linac3

J.P.Riunaud Villars 2004

Availability of Heavy Ions for SPS Fixed Target Physics

Planning of the Lead Ions for LHC :

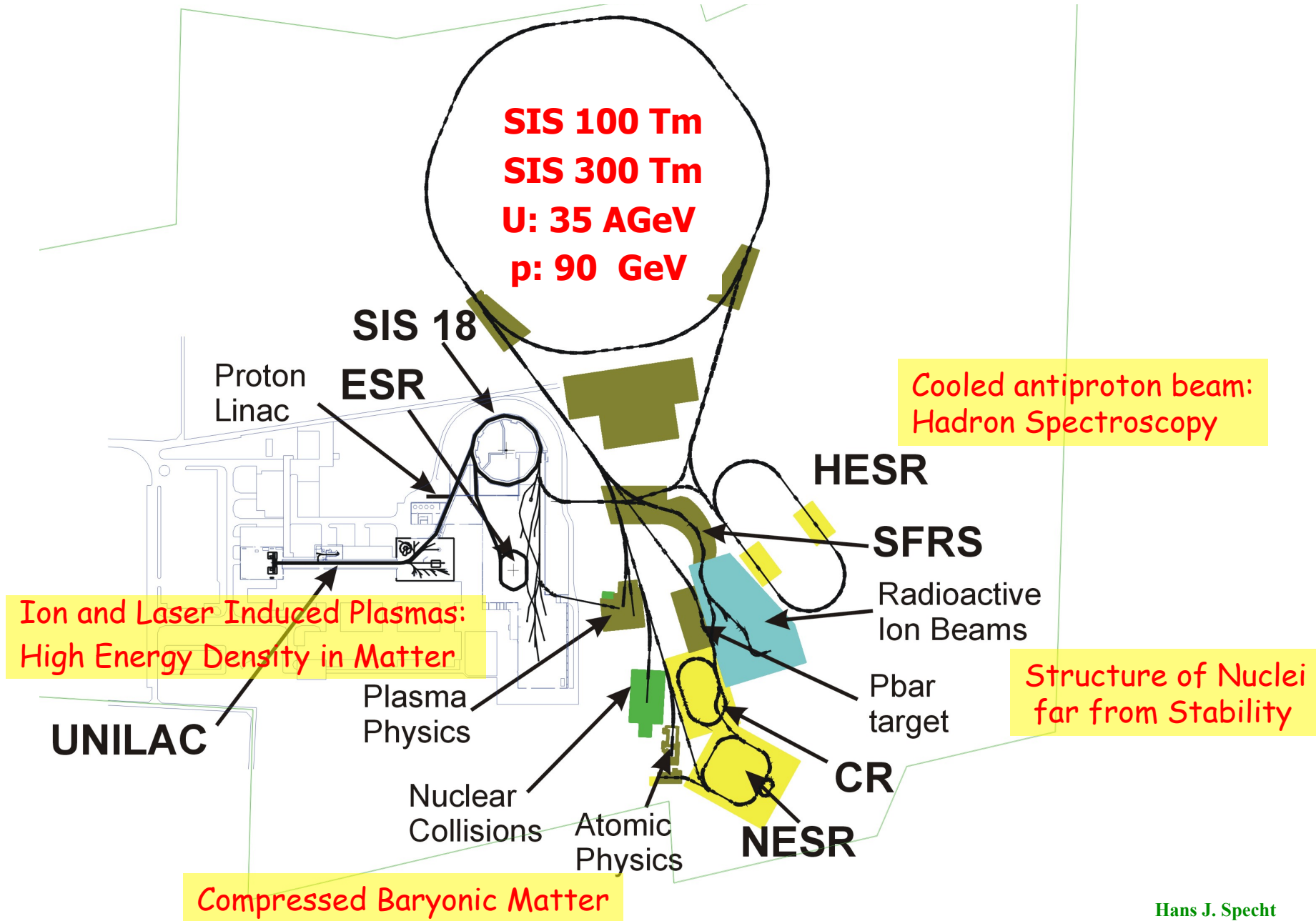
- Linac3 start up with Pb ions 02/2005
- Linac3 to LEIR injection line commissioning 06/2005 to 08/2005
- LEIR commissioning 08/2005 to 03/2006
- PS commissioning : 25 shifts in 2006 (6 dedicated MDs)
- SPS commissioning : 34 shifts in 2007 (24 dedicated MDs)
- LHC commissioning and physics with “early beam” : 2008

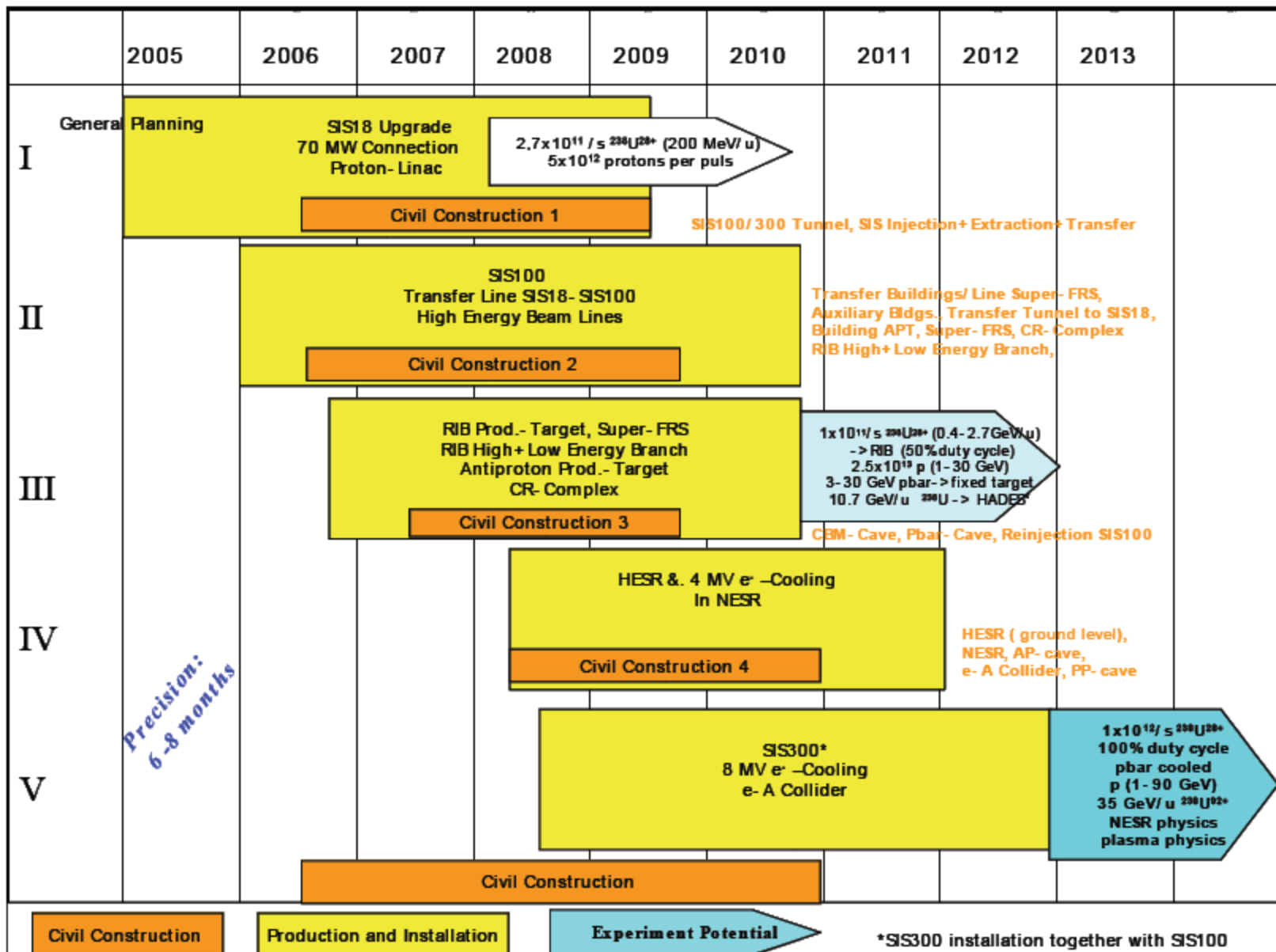
⇒ Lead ions can only be available for Fixed Target physics

- when they are available in the SPS and
- when they have been tuned for Fixed Target operation
(different beam in SPS than for LHC)

⇒ With the present I-LHC schedule, Lead ions can only be available after the ion LHC commissioning in 2008

The future Facility for Antiproton and Ion Research (FAIR)





Conclusions on future SPS Running

Full Energy

continuation of NA60 with Pb-Pb **(a must !)**

- low mass pairs
- intermediate masses
- J/ψ physics

Full and lower energies

(continuation of NA49)

continuation of NA60

- low mass pairs
- intermediate masses
- J/ψ physics

dedicated experiment on real photons

- better data for all p_T
- soft photons (a must!)

soft electron pairs?