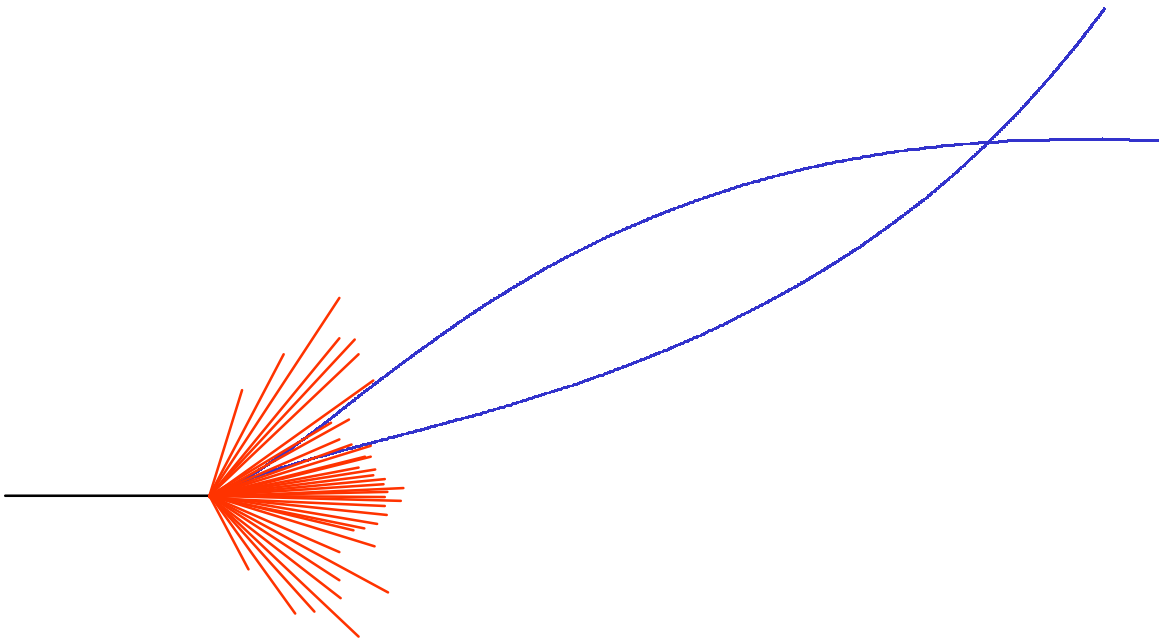
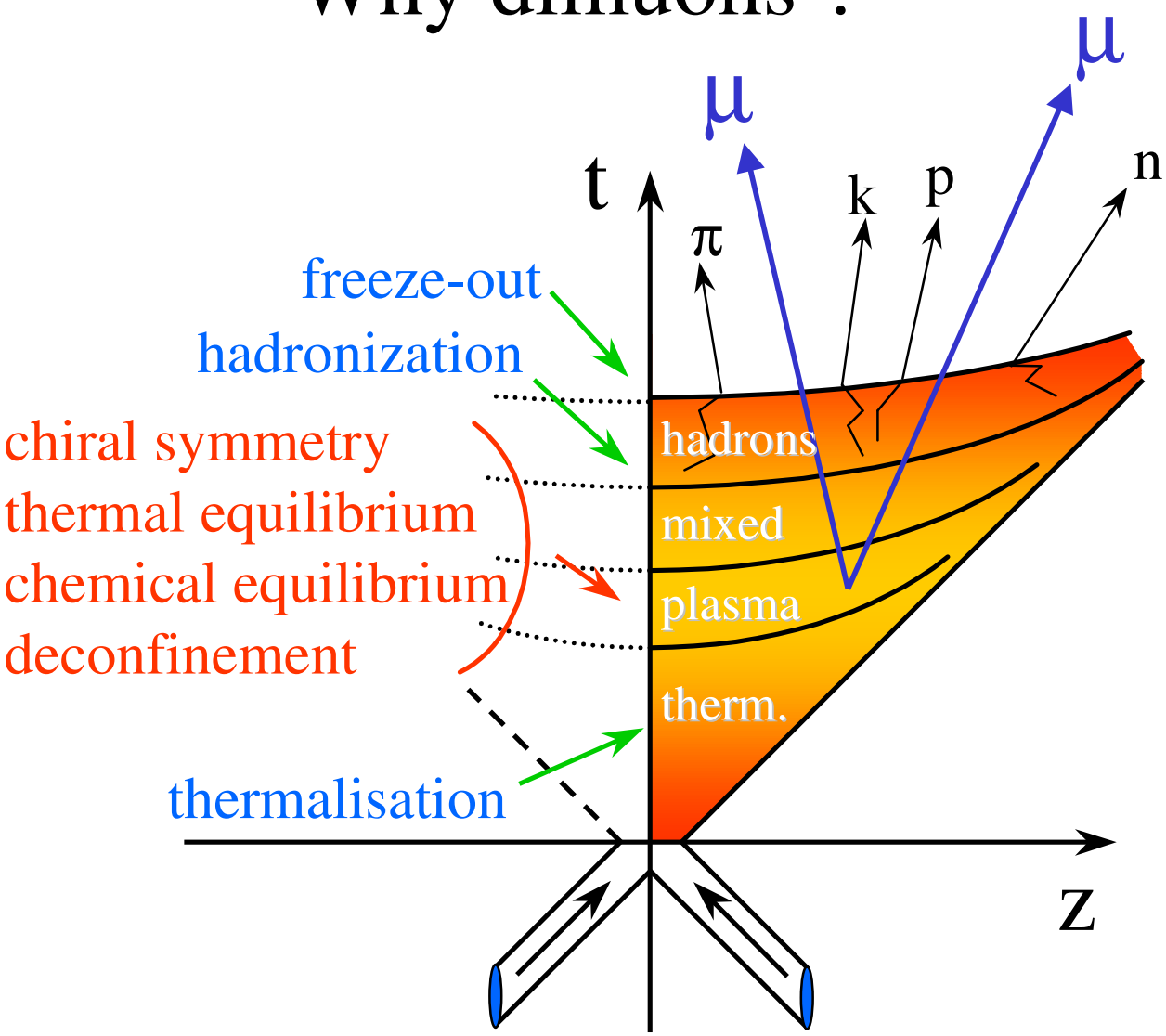
Dimuon experiments



O. Drapier,
IPN-Lyon, France

Why dimuons ?



- ✘ mass and width of resonances ($\rho \rightarrow \mu^+\mu^-$)
- ✘ thermal dileptons ($\mu^+\mu^-$)
- ✘ strangeness enhancement ($\phi \rightarrow \mu^+\mu^-$)
- ✘ suppression of heavy-quark bound states (J/ψ , Υ's $\rightarrow \mu^+\mu^-$)

Drawbacks

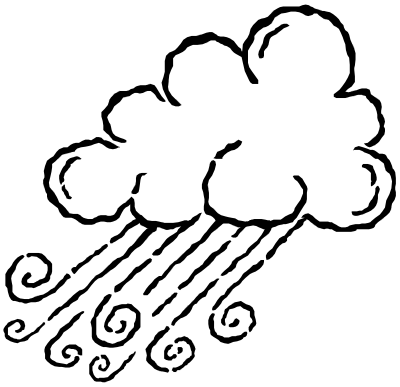
- ✘ small cross-sections
  - ✔ long running time
  - ✔ high luminosity
    - ✗ high beam intensity
      - ✓ pile-up
    - ✗ thick target
      - ✓ reinteractions
  - ✔ huge background from π and k decays
    - ✗ hadron absorber close to the vertex
      - ✓ multiple scattering + energy loss
        - resolution
        - acceptance

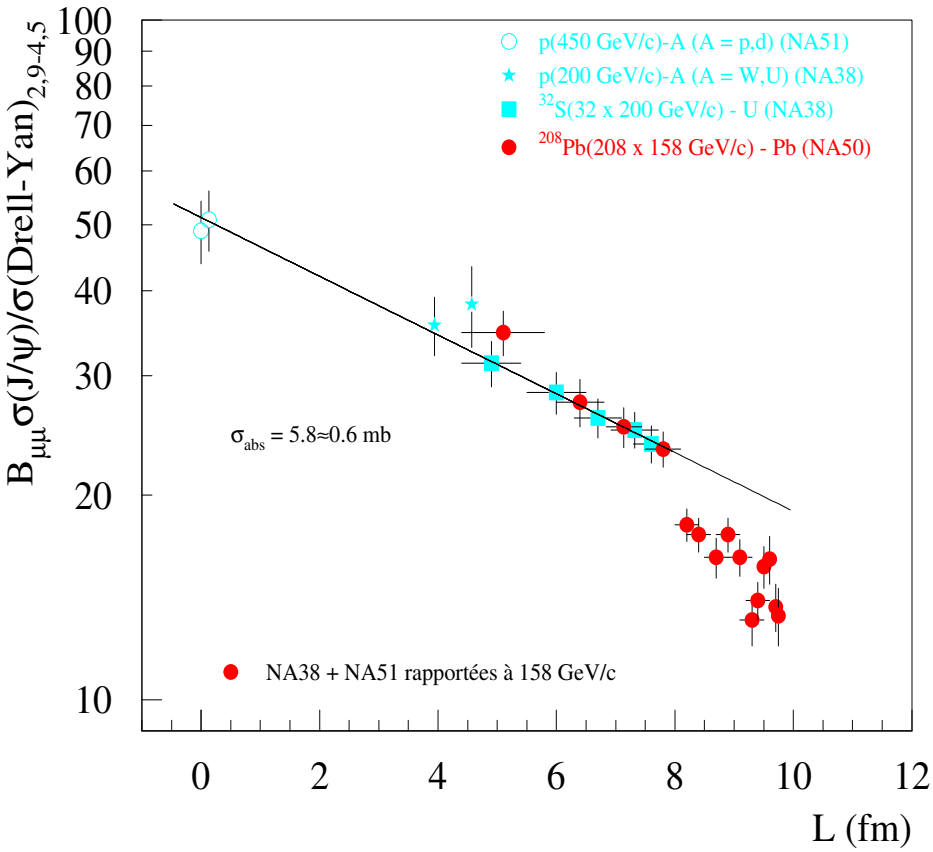
- ✘ ② is more complicated than ① !!!!
  - ✔ simple fiducial cut in 1-part. distributions
    - ✗ funny shapes in 2-part. acceptances

Additional complications

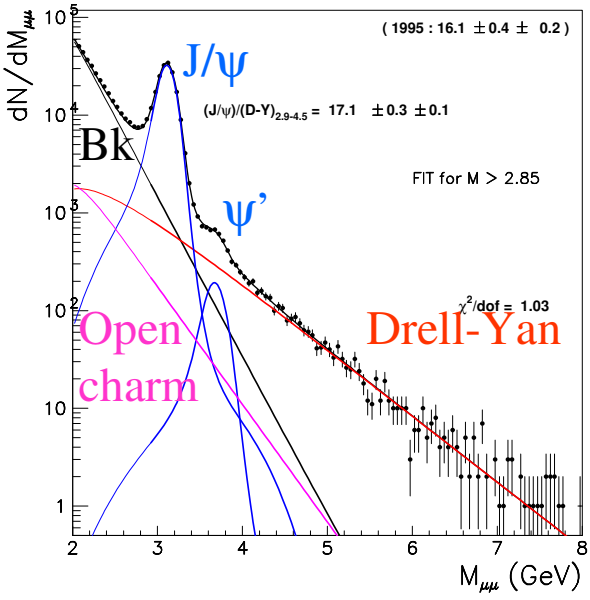
- ✘ comparison data ↔ theory
  - ✔ theory through detector simulation
  - ✔ data deconvolution
- ✘ enhancement, suppression
  - ✔ need for reference process(es)
    - ✗ what is “normal” and what is not ?
- ✘ fixed target experiments
  - ✔ peripheral events ?
    - ✗ empty target contribution
  - ✔ central events ?
    - ✗ pile-up
- ✘ SPS: from p-p to Pb-Pb
  - ✔ ≠ Z/A
    - ✗ isospin dependent processes
  - ✔ ≠ beam energies
    - ✗ ≠ N-N cross-sections
    - ✗ ≠ y coverage
  - ✔ compare ≠ systems at ≠ centralities ?

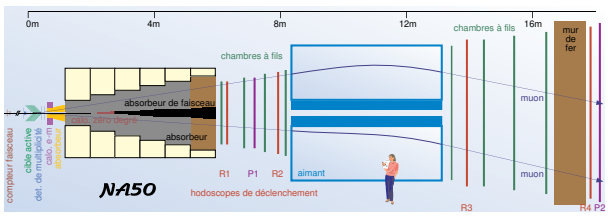
heaven-ion physics





purgatory

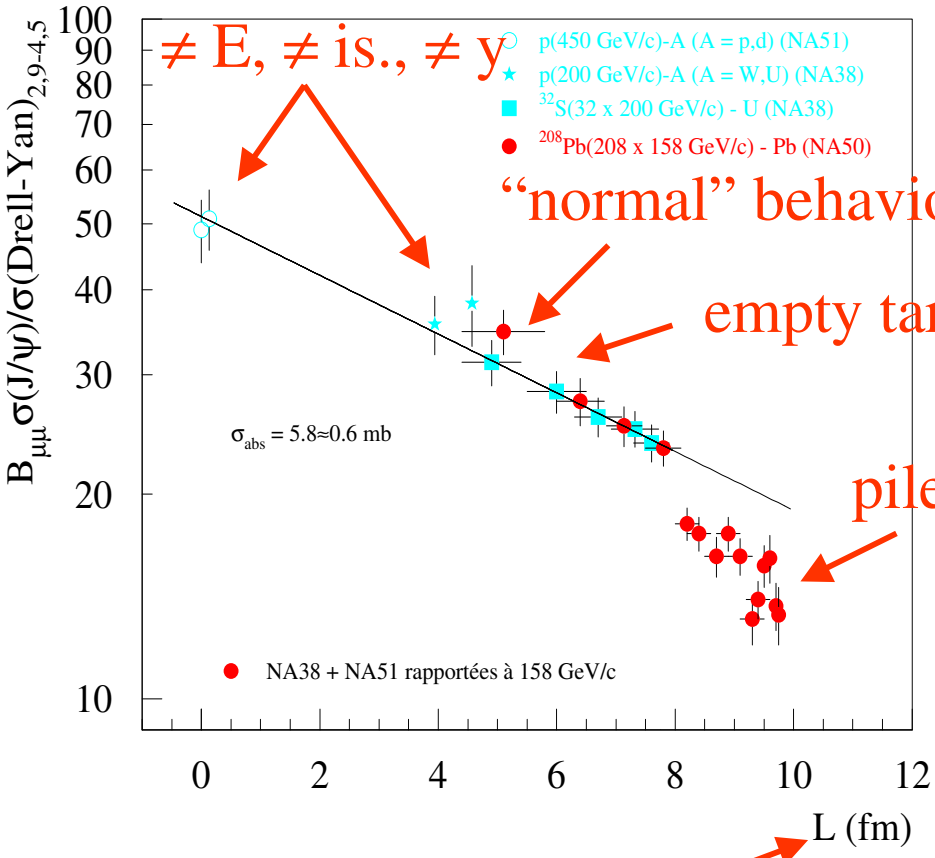




Chips'99, June 25, 1999

experimental hell

Outline



which reference ?

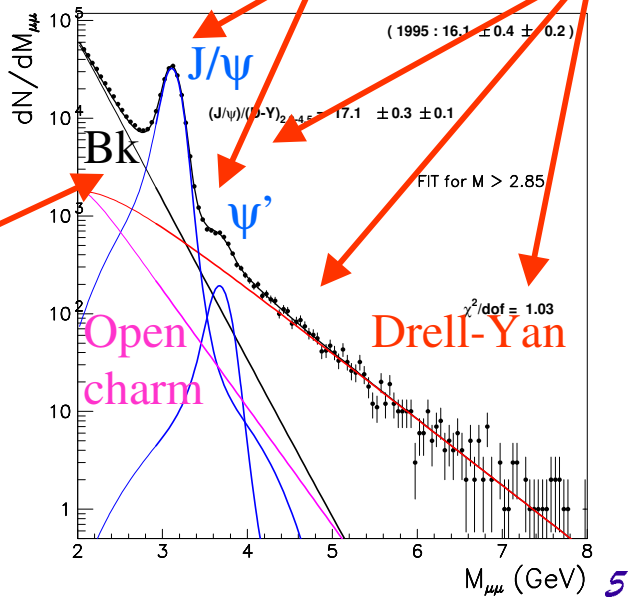
compare ≠ systems at ≠ centrality

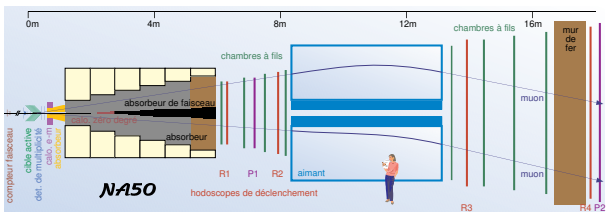
theory through detector ?
data deconvolution ?

resolution

acceptance

background

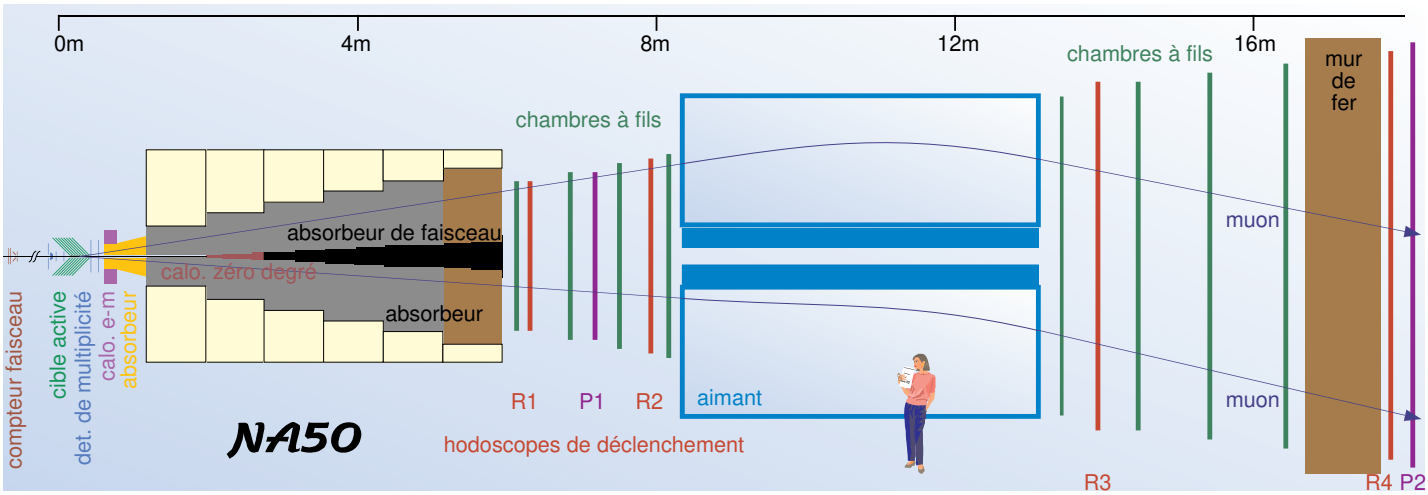


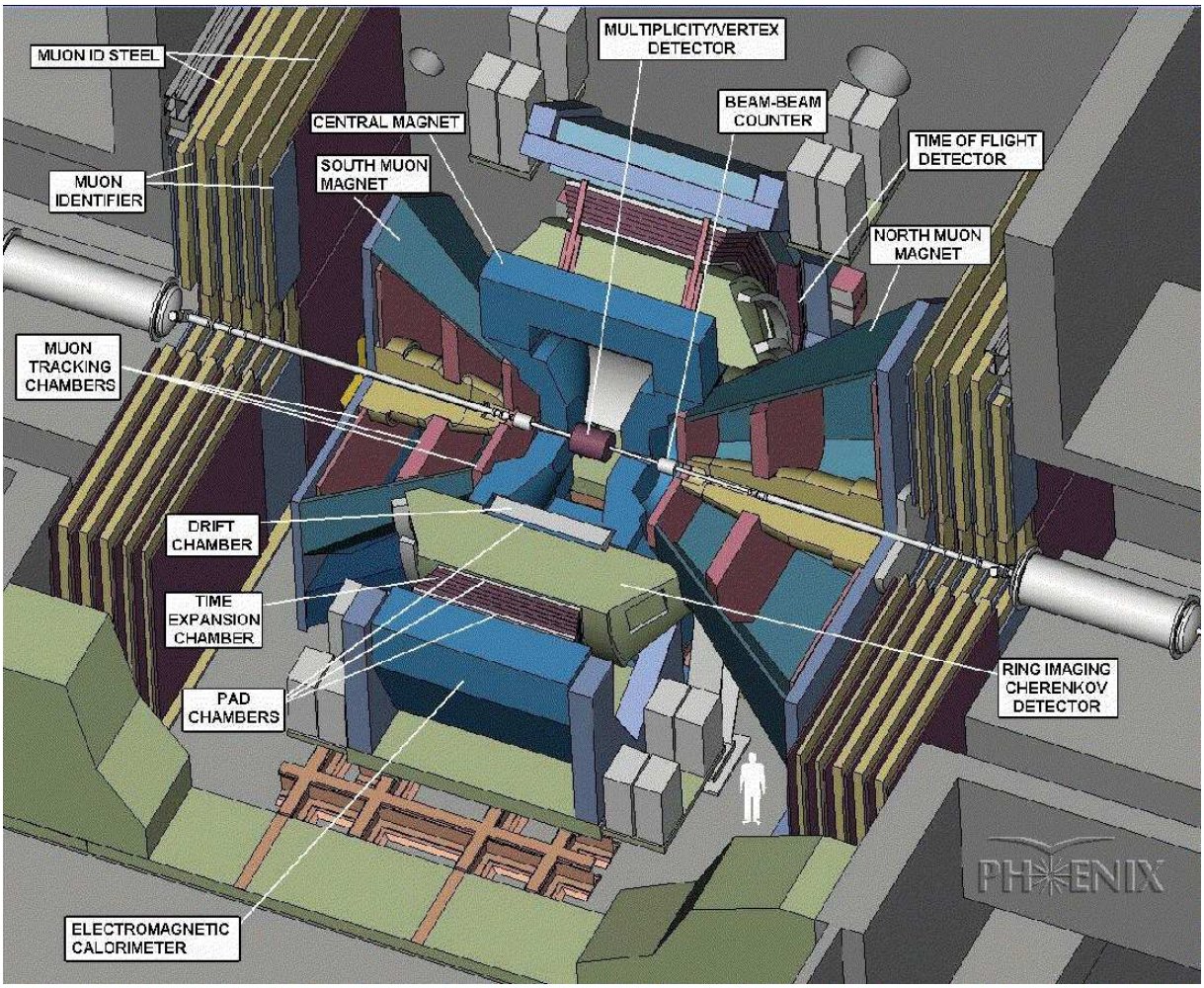


Experiments

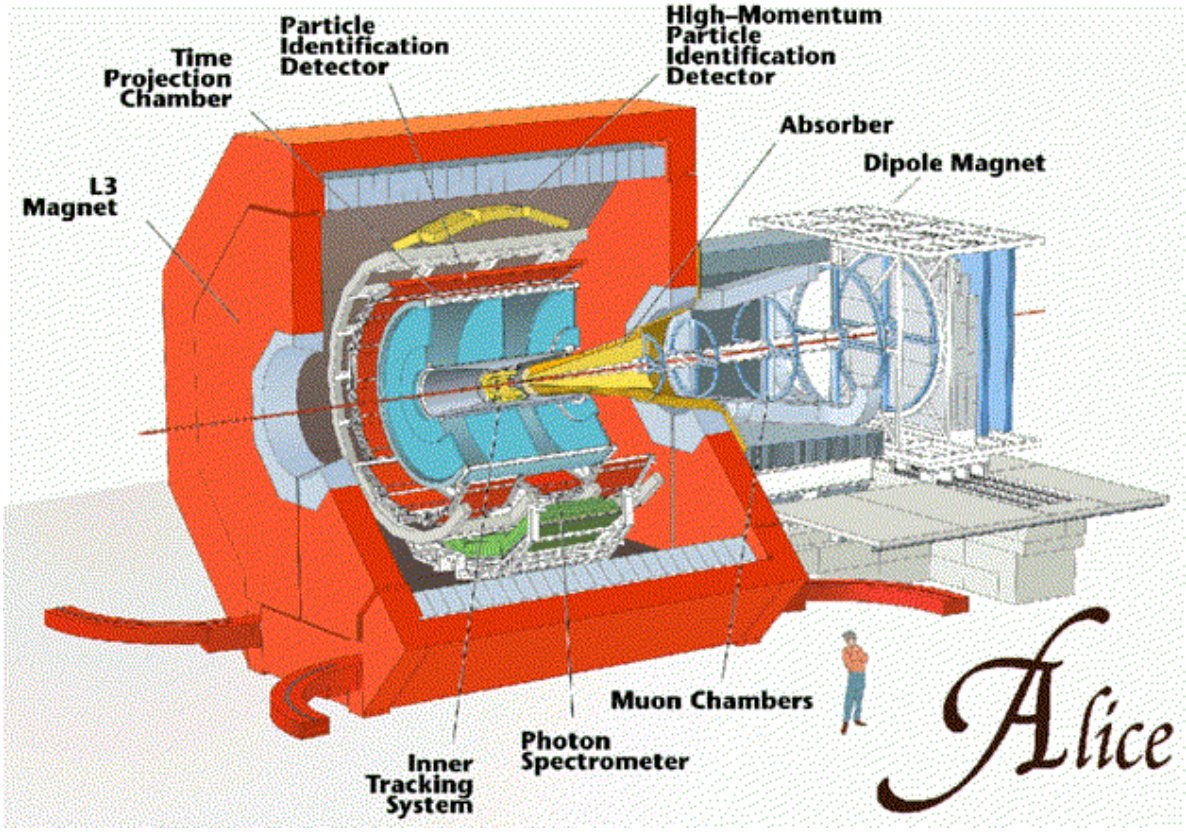
- ✘ high luminosity
  - ✔ event pile-up detection
  - ✔ thick target (e.g. NA50)
    - ✗ is segmented to avoid reinteraction of secondaries
      - ✓ active target to detect vertex position
- ✘ huge background
  - ✔ hadron absorber as close as possible to avoid decays (e.g. NA50, Alice)
    - ✗ jeopardize the resolution
  - ✔ high magnetic field (e.g. CMS)
    - ✗ momentum cut

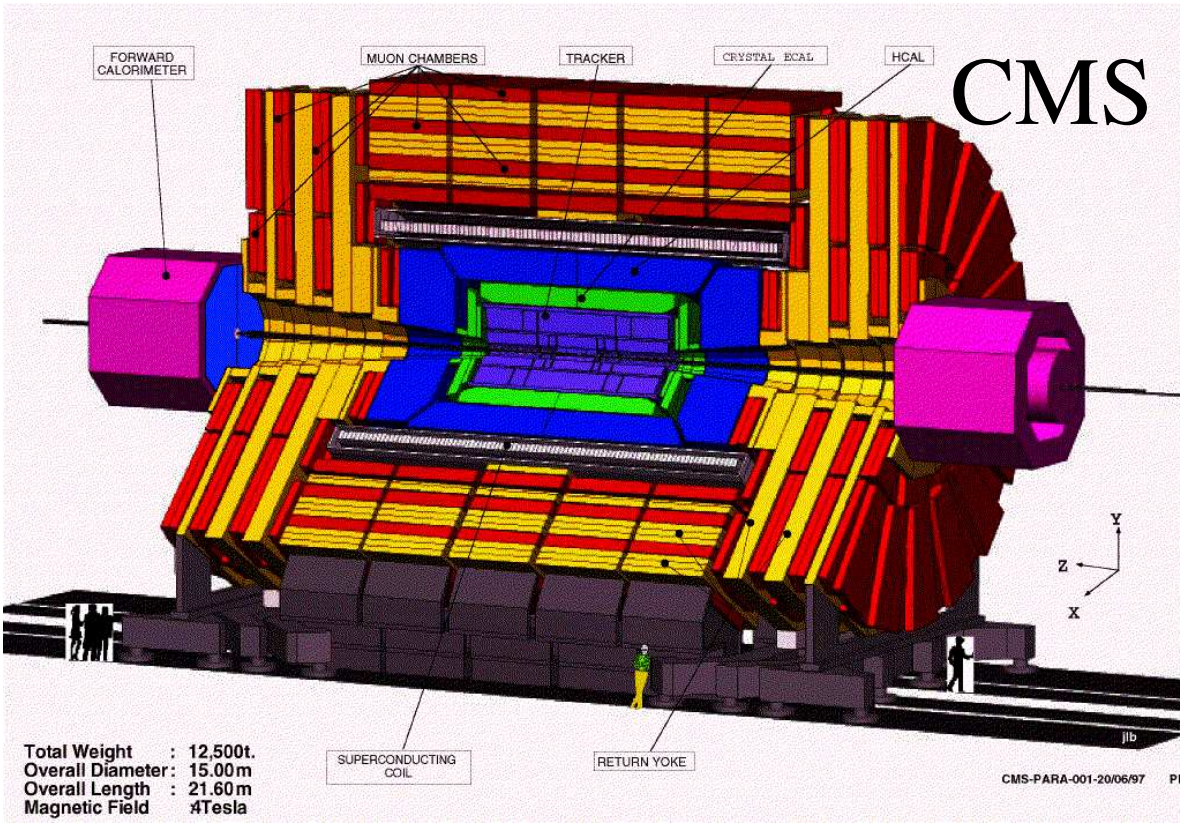
Experiments





Experiments





Background

- ✘ huge background despite the absorbers and magnetic field
  - ✔ $\pi \rightarrow \mu^{\pm}\nu$ $k \rightarrow \mu^{\pm}\nu$
  - ✔ but also $\rightarrow \mu^{+}\mu^{+}$ $\mu^{-}\mu^{-}$
  - ✔ record $\mu^{+}\mu^{+}$ and $\mu^{-}\mu^{-}$

$$N^{++} = \int p(N^{+}) \frac{N^{+}(N^{+}-1)}{2} \alpha_{+}^{2} A^{++} dN^{+} \quad \text{(same for } --\text{)}$$

$$N_{Bk}^{+-} = \int p(N^{+}, N^{-}) N^{+} N^{-} \alpha_{+} \alpha_{-} A^{+-} dN^{+} dN^{-}$$

$$N_{Bk}^{+-} = A^{+-} < N^{+} >< N^{-} > \alpha_{+} \alpha_{-}$$

$$N^{++} = \frac{1}{2} A^{++} \alpha_{+}^{2} (< N^{+2} > - < N^{+} >) \quad \text{(same for } --\text{)}$$

if poisson $(< N^{2} > - < N >^{2}) =< N >$

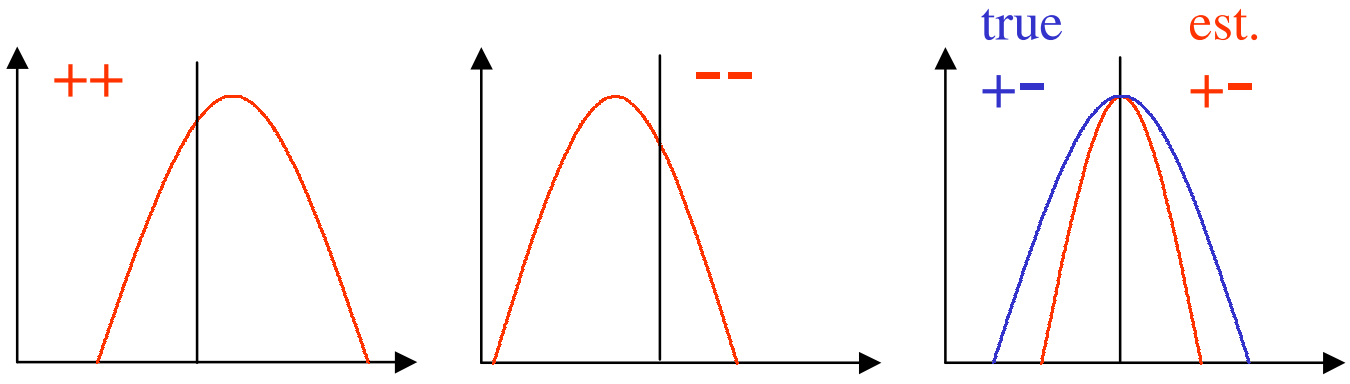
$$N_{Bk}^{+-} = 2 \frac{A^{+-}}{\sqrt{A^{++} A^{--}}} \sqrt{N^{++} N^{--}}$$

if acceptance independent of the charge of the other μ

$$N_{Bk}^{+-} = 2R\sqrt{N^{++} N^{--}}$$

Background

- ✘ R accounts for deviation from poisson
  - ✔ for example: due to correlation
  - ✔ depends on
    - ✗ multiplicity (e.g. charge conservation)
    - ✗ experimental set-up
- ✘ does not account for correlated back.
  - ✔ open charm, open beauty ...
- ✘ the acceptance of one μ must be independent on the charge of the other μ
  - ✔ true for integrated yield
    - ✗ except if trigger correlation
  - ✔ may be false for differential spectra if asymmetric acceptances



Background

- ✘ Specific cut to avoid asymmetry
  - ✔ "image cut"
    - ✗ reject tracks which "charge conjugate" would have been outside acceptance
- ✘ combinatorial background calculation
  - ✔ yield given by 2R etc …
  - ✔ shape from mixed events technique
    - ✗ separate + and - from ++ and --
    - ✗ build fake +- with individual muons
  - ✔ huge statistics
    - ✗ good precision but huge cpu
  - ✔ combinations must be exhaustive
    - ✗ mean value of n sub-samples (1/n)
- ✘ in any case, R determined by
  - ✔ monte-carlo
  - ✔ different absorbers

Detector effects

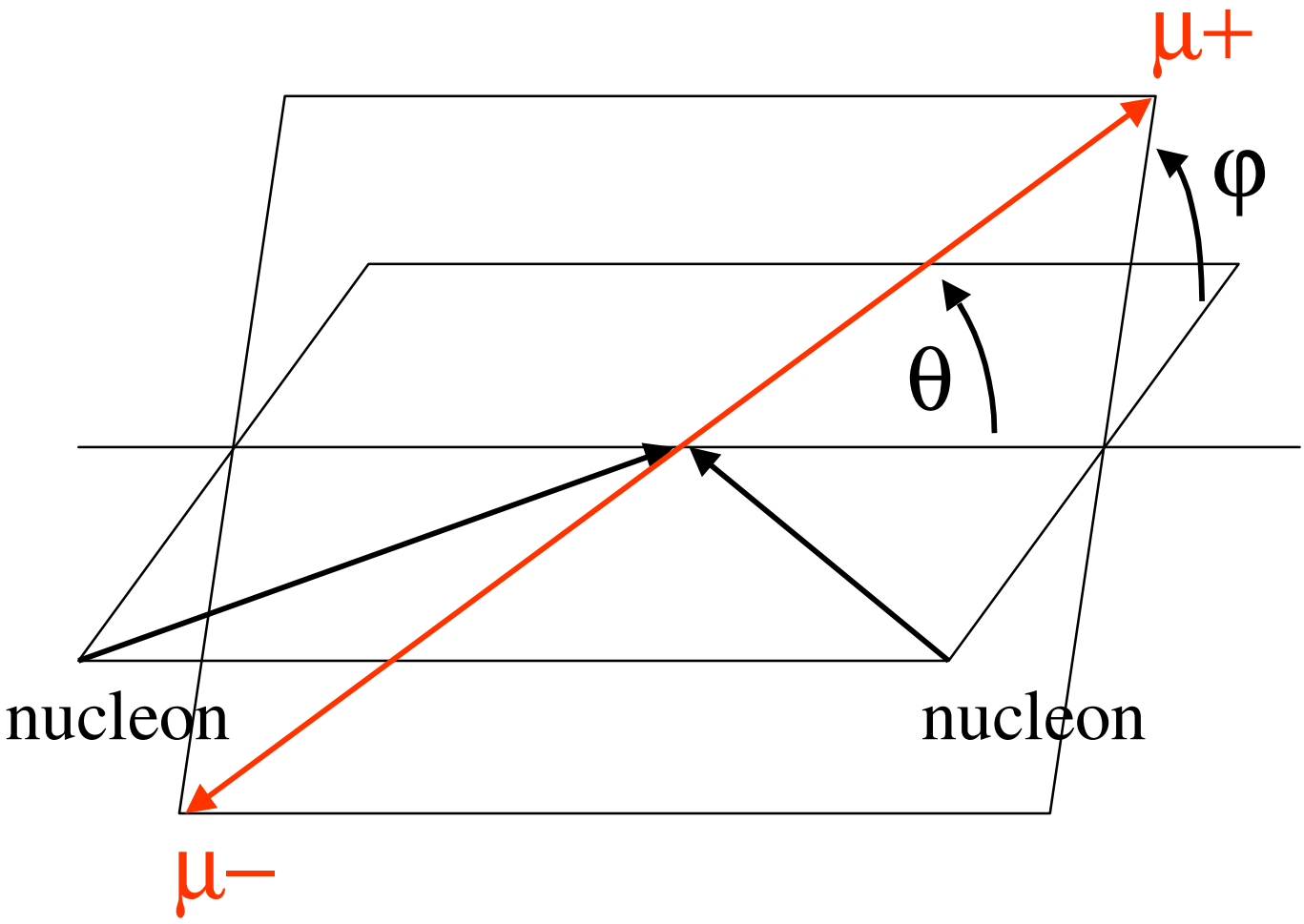
- ✘ acceptance and resolution
  - ✔ acceptance $A(x)$
  - ✔ resolution $S(x'|\,x)$

$$D(x') = \int S(x'|\,x)\, A(x)\, \Phi(x)\, dx$$

- ✘ determine distribution ϕ(x)
- ✘ kinematical variables
  - ✔ 2 muons → 8 parameters
    - ✗ 2 masses Mμ
  - ✔ 6 independent parameters :
    - ✗ invariant mass M
    - ✗ transverse momentum P_T
    - ✗ rapidity y_{cm}
    - ✗ polar angle in C.S. frame $\cos\theta_{cs}$
      - ✓ angle C.S. / reaction plane
      - ✓ angle of reaction plane / lab

(Collins-Soper frame)

- linked to the dimuon rest frame

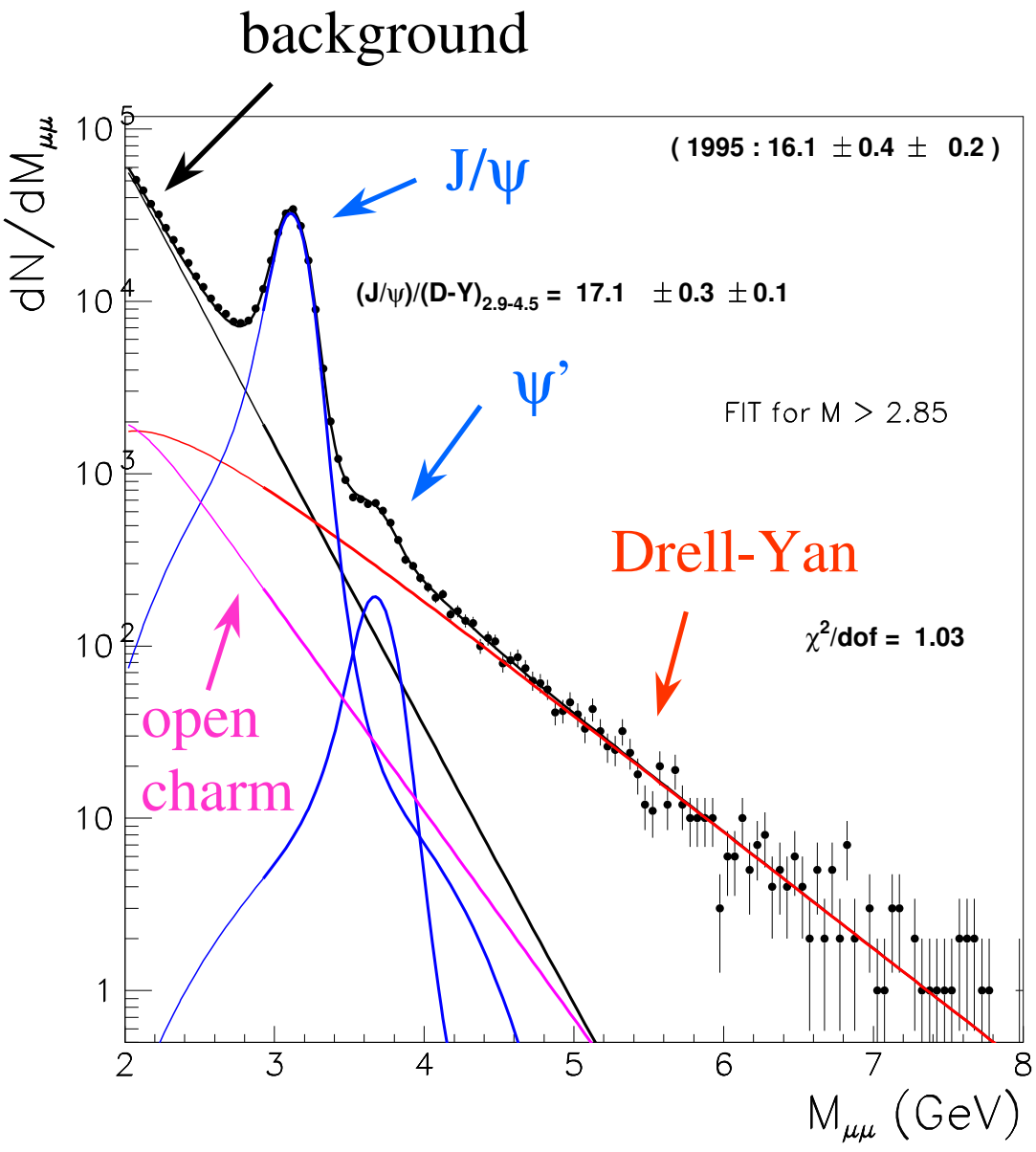


Comparison data - theory

- ✘ simulate theory through detector and compare to data
  - ✔ who does the work ?
    - ✗ experimentalists ?
      - ✓ ok if "theory" simple enough !
        - Higgs with a given mass
        - resonance, etc …
      - ✓ not always the case for dimuon predictions !
        - e.g.: thermal dimuons !!!
    - ✗ theorists ?
      - ✓ ok if "experiment" simple enough !
        - 1 dimensional acceptance
        - well parametrized smearing
      - ✓ never the case for dimuon experiments !
    - ✗ both ?
      - ✓ experimentalists provide theorists with simple simulation of detector effects
- ✘ try to unfold data

Comparison data - theory

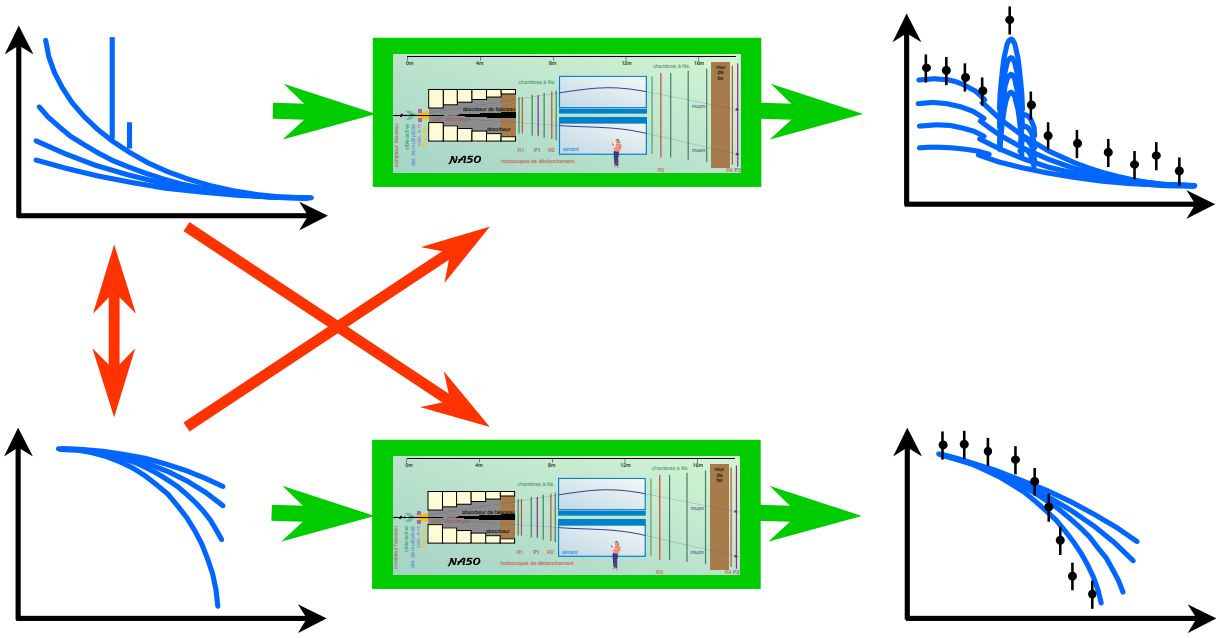
- fit the data with shapes given by the simulation
- extract the amplitudes of each process



Deconvolution methods

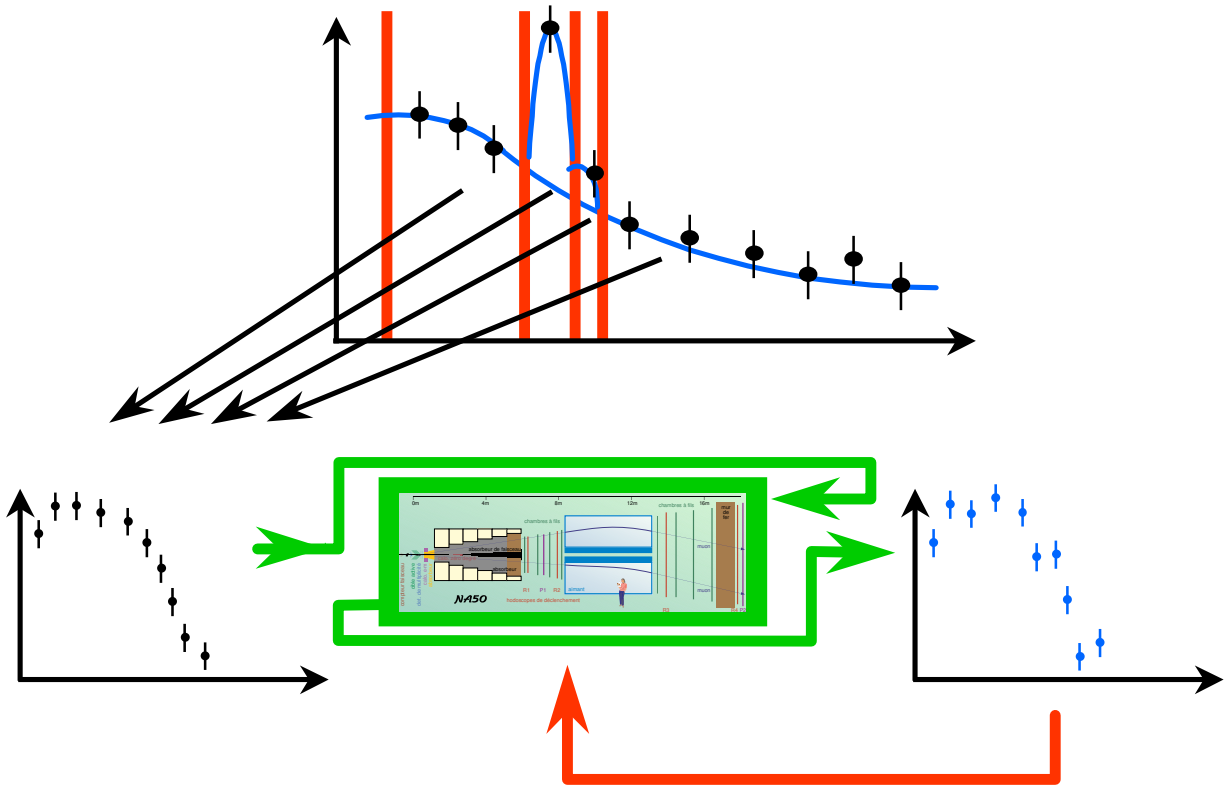
- ✘ discretize using histograms
  - ✔ detector considered as a transfer matrix
  - ✔ determined by monte-carlo
  - ✔ but in principle 8 dimensions !!!
    - ✗ 4 in the physics space
    - ✗ 4 in the reconstructed space
  - ✔ the detector introduces correlations between the different variables
    - ✗ the mass resolution may depend on Pt
      - ✓ the way the mass resolution depends on Pt may be different for small and large y
        - etc ...
- ✘ impossible to invert 2x4D matrix
  - ✔ in addition inverse may have huge fluctuations due to finite statistics

Fit through 1D matrices



- ✘ 1D approximation: separability
  - ✔ correlations between variables due to the detector
    - ✗ distribution B changes the matrix A
      - ✓ iterative procedure
  - ✔ correlations between variables due to physics
    - ✗ impossible to take into account
  - ✔ one must assume the shapes

“inverse” smearing matrix



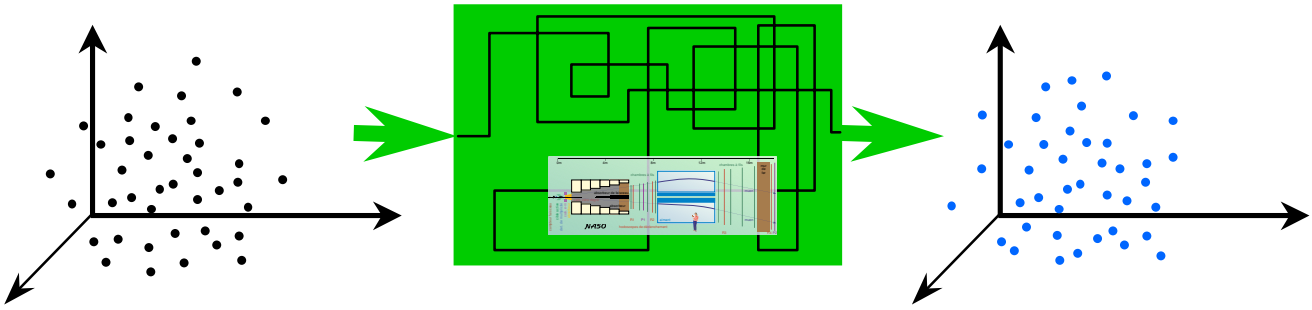
- ✘ detector correlations
  - ✔ distribution B changes the matrix A
  - ✔ distribution A changes the matrix A !!!!
    - ✗ iterative procedure
- ✘ correlations between variables due to physics
    - ✗ impossible to take into account

Possible 4D method

- ✘ based on image restoration methods extended to 4D
  - ✔ in principle:
    - ✗ account for detector correlations
    - ✗ allows to preserve physics correlations
    - ✗ no shapes assumed for distributions

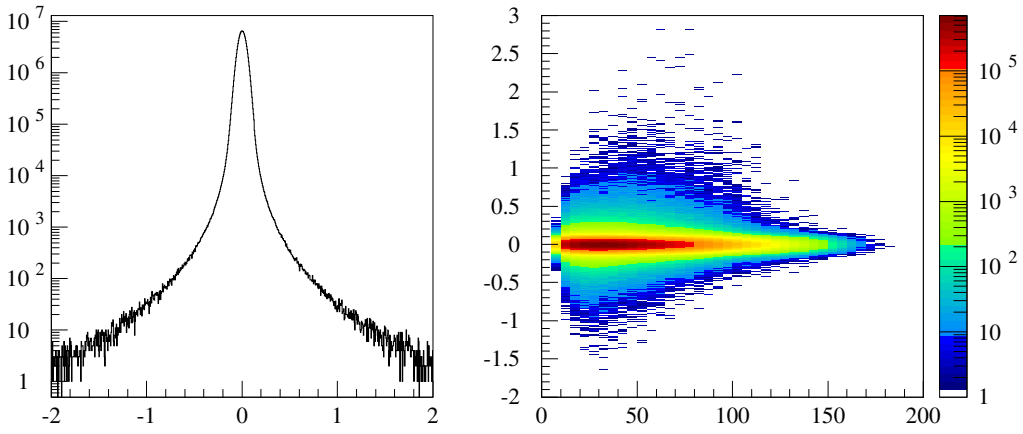
$$O^n(j) = O^{n-1}(j) \sum S(i \mid j) \frac{D(i)}{I^{n-1}(i)}$$

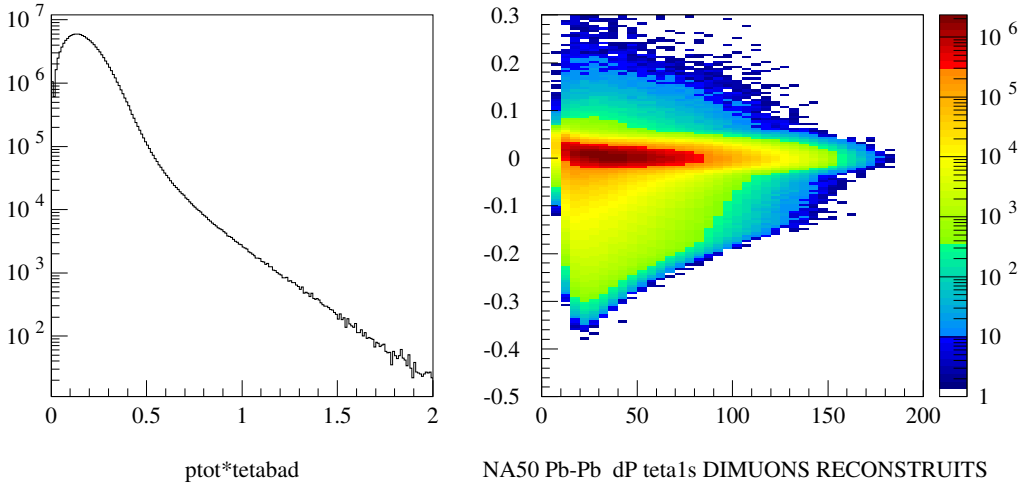
$$O^n(j) = \phi^n(j) * A(j)$$



- ✘ S(i|j) $(70*50*30*32)^2 \sim 10^{13}$ terms!
  - ✔ precision → 1000 evts/cell
  - ✔ impossible to compute and store

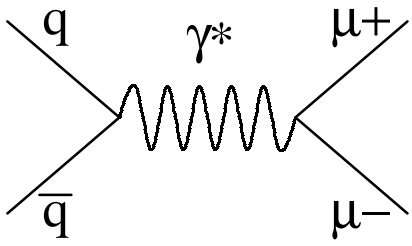
- ✘ solution : S(i|j) computed “on-line”
  - ✔ each time the program needs it
    - ✘ from single muon characteristics
      - ✓ dimuons cut into 2 muons
      - ✓ single muons are smeared
      - ✓ smeared dimuon is recomputed

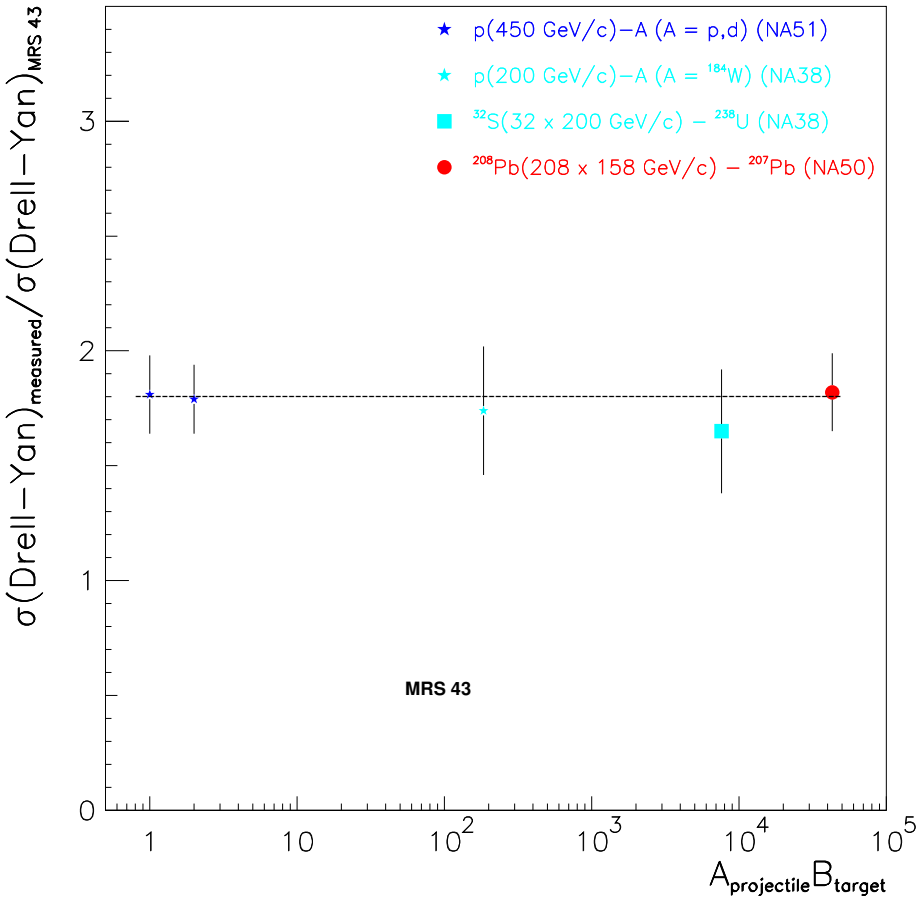




Reference process

- ✘ enhancement, suppression …
  - ✔ … with respect to simple superposition of nucleon-nucleon collisions
  - ✔ reference = prop. to N-N collisions
    - ✗ e.g. Drell-Yan process:
      - ✓ poor statistics
    - ✗ at LHC … Z boson ?





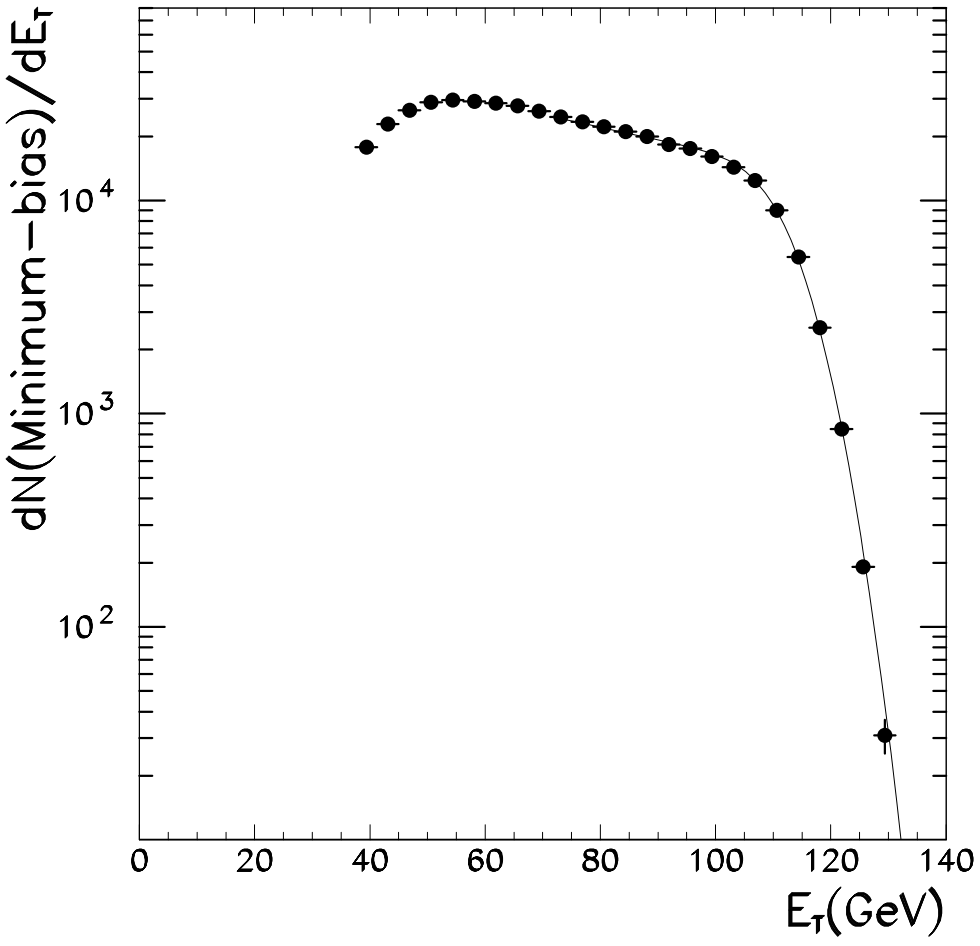
Other reference used in NA50

- ✘ "mimimum bias" events
  - ✔ not proportional to N-N collisions but:

$$\frac{J/\Psi}{DY} = \frac{J/\Psi}{MB} \times \frac{MB}{DY}$$

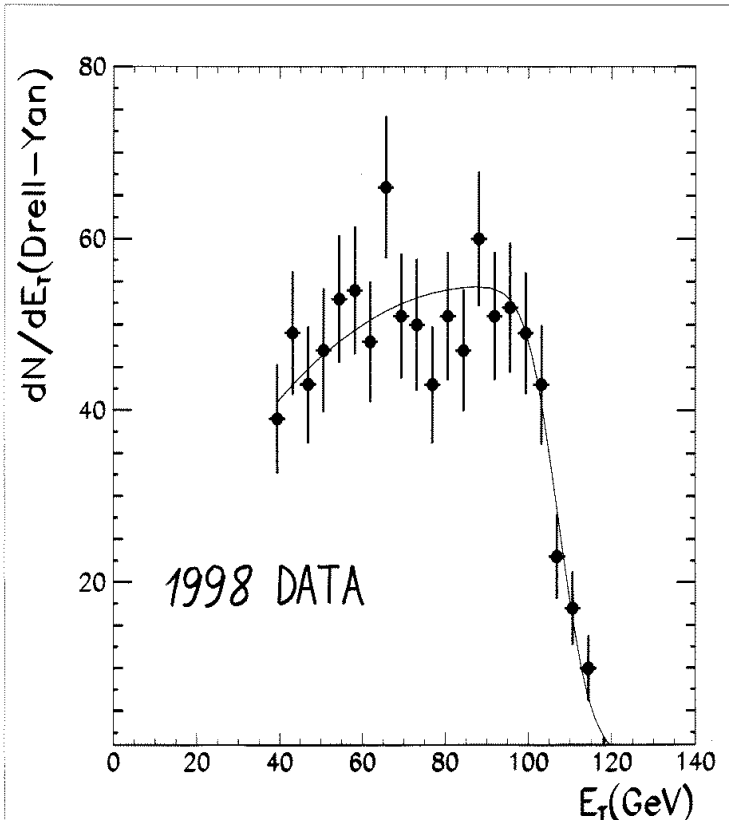
$$\frac{MB}{DY} = \frac{1}{N_{coll}} \quad \text{can be computed}$$

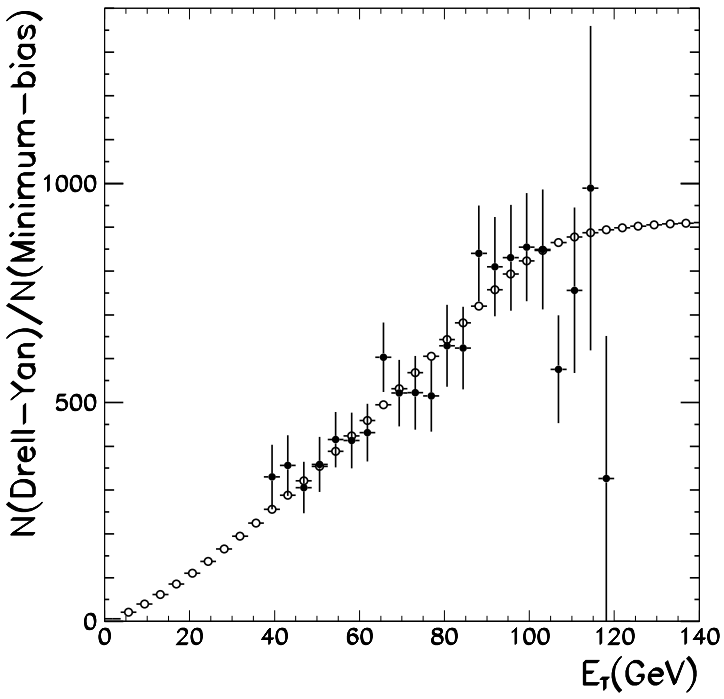
  - ✔ min. bias spectrum fitted "a la Glauber"



Min. bias reference

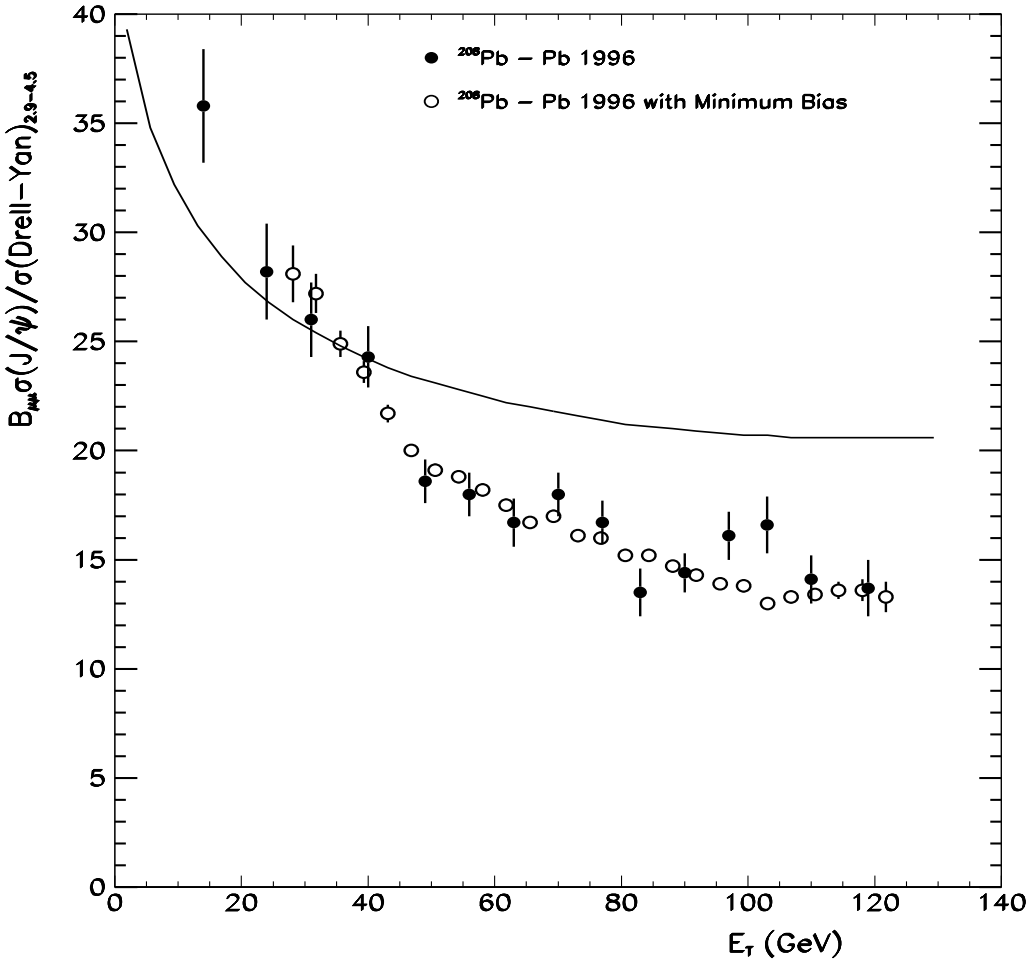
- Drell-Yan well reproduced with the same parameters





- Ratio equal to the number of nucleon-nucleon collisions

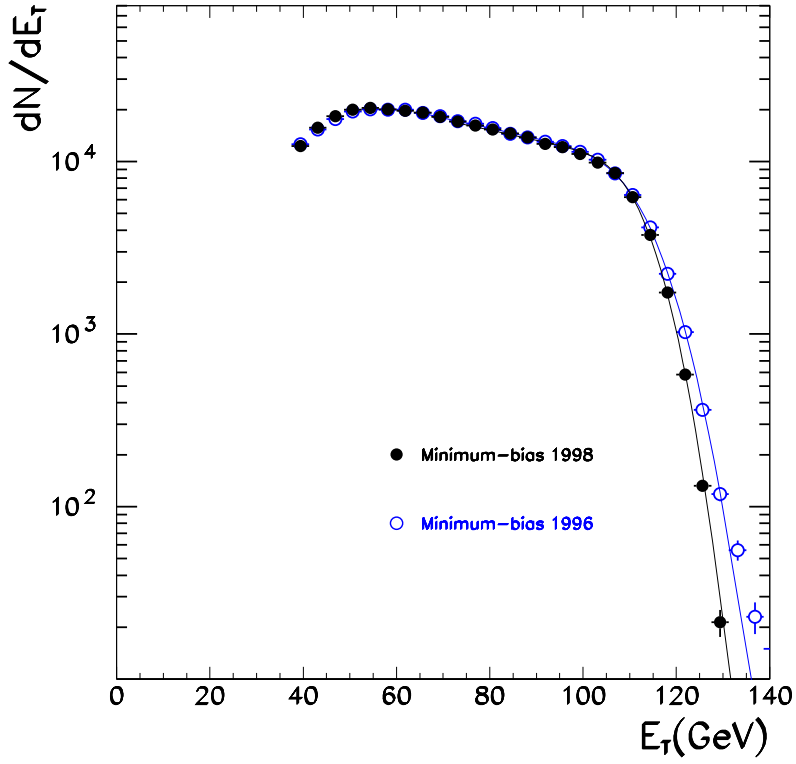
Result



- ✘ more statistics ...
  - ✔ less fluctuations and more points
- ✘ … but possible additional biases
  - ✔ the "signal" and the reference have very different trigger conditions
    - ✗ hiden efficiencies do not cancel out
    - ✗ possible contaminations in min bias

Contaminations

- ✘ peripheral events can be contaminated by interactions from target environment
  - ✔ air, beam pipe windows, etc
- ✘ central events can be contaminated by peripheral or semi-central ones
  - ✔ wrong centrality measurement due to event pile-up
    - ✗ same minimum bias spectrum (Pb-Pb)
      - ✓ 30 % λint (96) and 7 % λint (98)



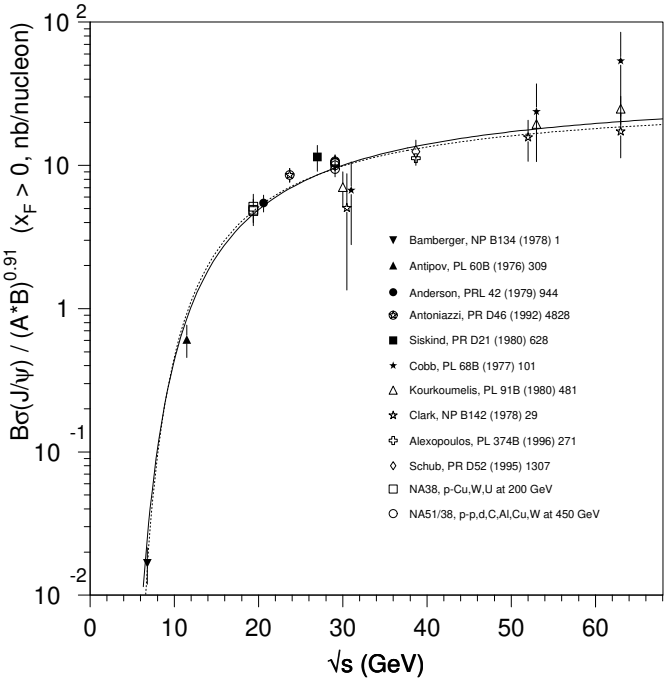
Different experimental conditions

- ✘ Comparison between different systems
  - ✔ different isospin contents
    - ✗ taken into account for Drell-Yan by normalization to p-p collisions

$$\sigma_{AB}^{plot} = \sigma_{AB}^{data} \times AB \times \frac{\sigma_{p-p}^{MRS}}{\sigma_{AB}^{MRS}}$$

  - ✔ different energies
    - ✗ all systems rescaled to 158 GeV/c
      - ✓ MRS for D.Y.
      - ✓ "schuler parametrization" for J/ψ

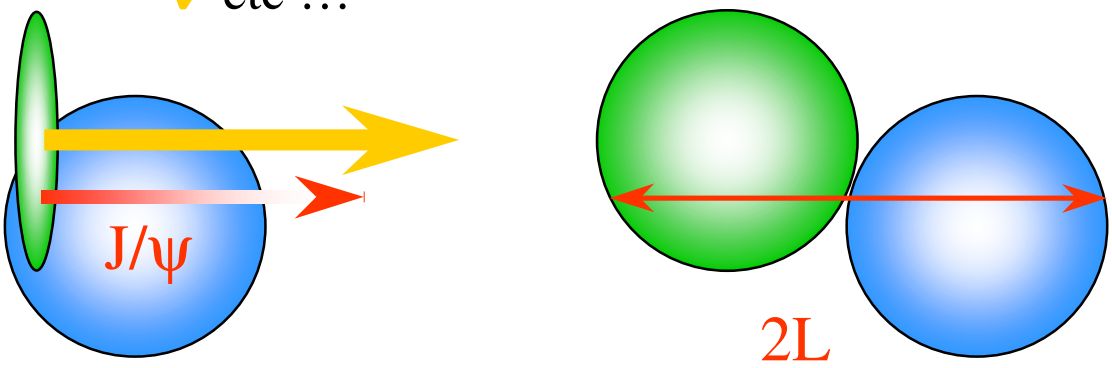
$$\sigma_{c\bar{c}} \propto (1 - M / \sqrt{s})^{12}$$



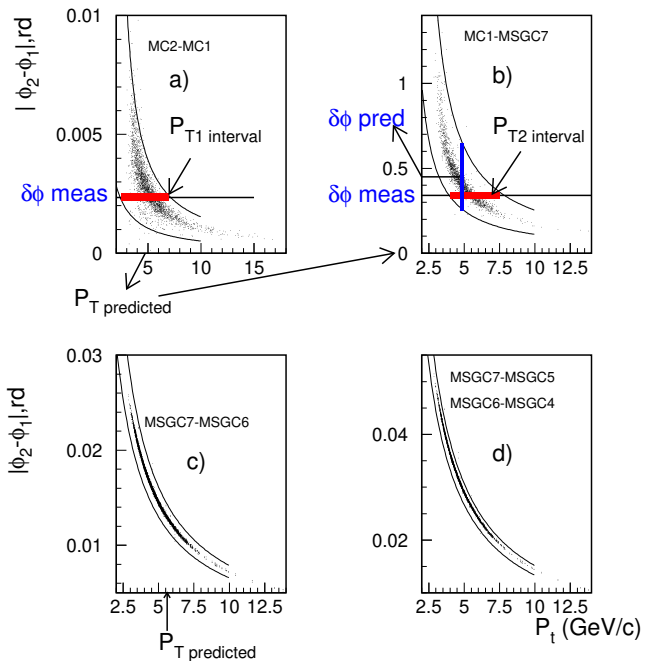
  - ✔ different kinematical domains
    - ✗ all systems rescaled to 0<y<1

compare ≠ systems at ≠ centralities ?

- ✘ The same E_T, E_{ZDC} or multiplicity does not have the same meaning for different systems and different energies
  - ✔ need for a common scale
    - ✗ no universal scale
      - ✓ energy density
      - ✓ number of participants (or wounded nucl.)
      - ✓ reduced impact parameter
      - ✓ % of total cross-section
      - ✓ "thickness" of nuclear medium
      - ✓ etc …



- ✘ future: we'll have to be creative !

In the future

- ✘ interpretation problems remain
  - ✔ comparison SPS-RHIC-LHC
- ✘ technical challenges
  - ✔ particle multiplicity
    - ✗ uo to 8000 charged particles / rapidity unit at y=0 for LHC energies
      - ✓ background impacts in the tracking devices
        - tracking efficiency
      - ✓ decay muons
        - signal/background ratio
    - ✗ e.g. tracking algorithm for CMS: