Know How at LLR

Ultra-granular calorimetry

AFTER vs CHIC

AFTER vs CHIC

- **AFTER project**
  - LHC fixed target experiment
  - Multi-purpose detector
  - Test negative x_F region ($x_F \in [-1,0]$)
  - Must be designed to run in p+p, p+A, A+A ➔ high occupancy
  - Long term
- **CHIC project**
  - SPS fixed target experiment
  - Dedicated to charmonium physics
  - Test positive x_F region ($x_F \in [0,1]$)
  - Must be designed to run in p+p, p+A, A+A ➔ high occupancy
  - middle term
  - could be used as a demonstrator for after

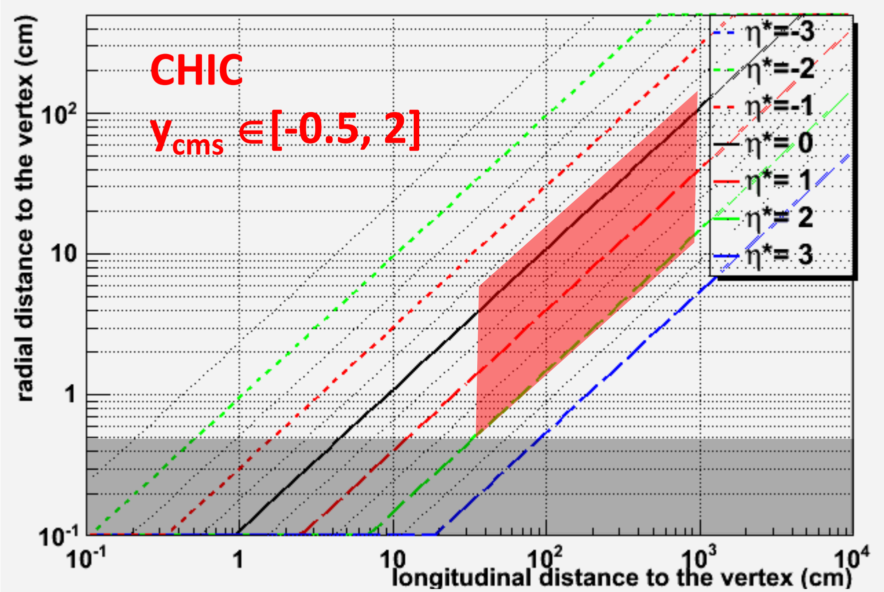
Charmonia in Heavy Ion Collisions

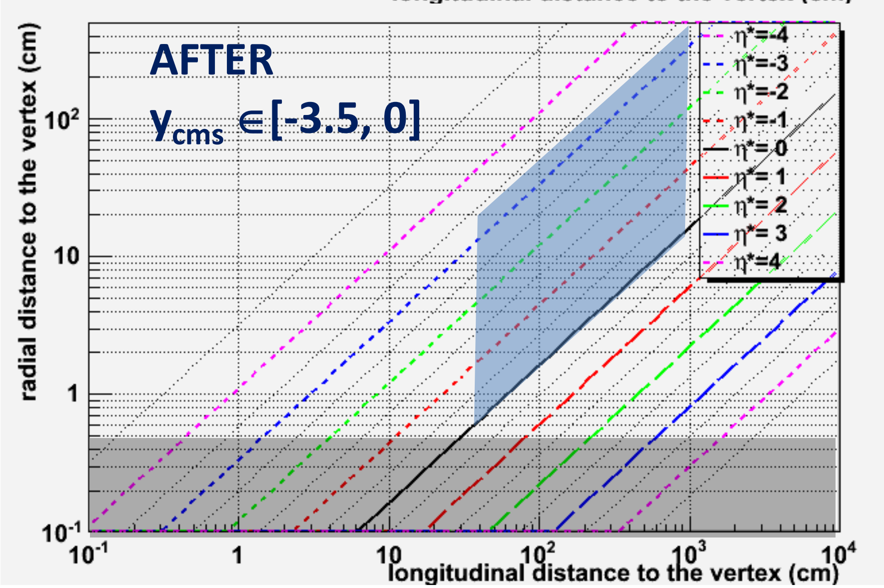
- **What is CHIC ?**
  - CHIC is a project of a fixed target experiment to be operated in Pb+Pb collisions at SPS energies ($\sqrt{s}$~20 GeV)
  - **Benchmark 1: χ_c production in Pb+Pb at $\sqrt{s}$=17 GeV**
    - Measure χ_c production within $y_{cms} \in [-0.5,0.5]$
    - Test charmonium sequential suppression in a QGP
    - Complementary with J/Ψ and Υ measurements at RHIC/LHC
    - χ_c production in A+A is currently unreachable at any facility
  - **Benchmark 2: charmonia production in p+A within $y_{cms} \in [-0.5, 2]$**
    - Precise measurement of Cold Nuclear matter effects at SPS
    - Test a wide rapidity range (up to $y=2 \equiv x_F$~1)
    - Gluon shadowing at SPS energies
    - Energy loss, hadronisation time
  - Other physics subjects: Drell-Yan, open charm, photons, hadrons

CHIC and AFTER

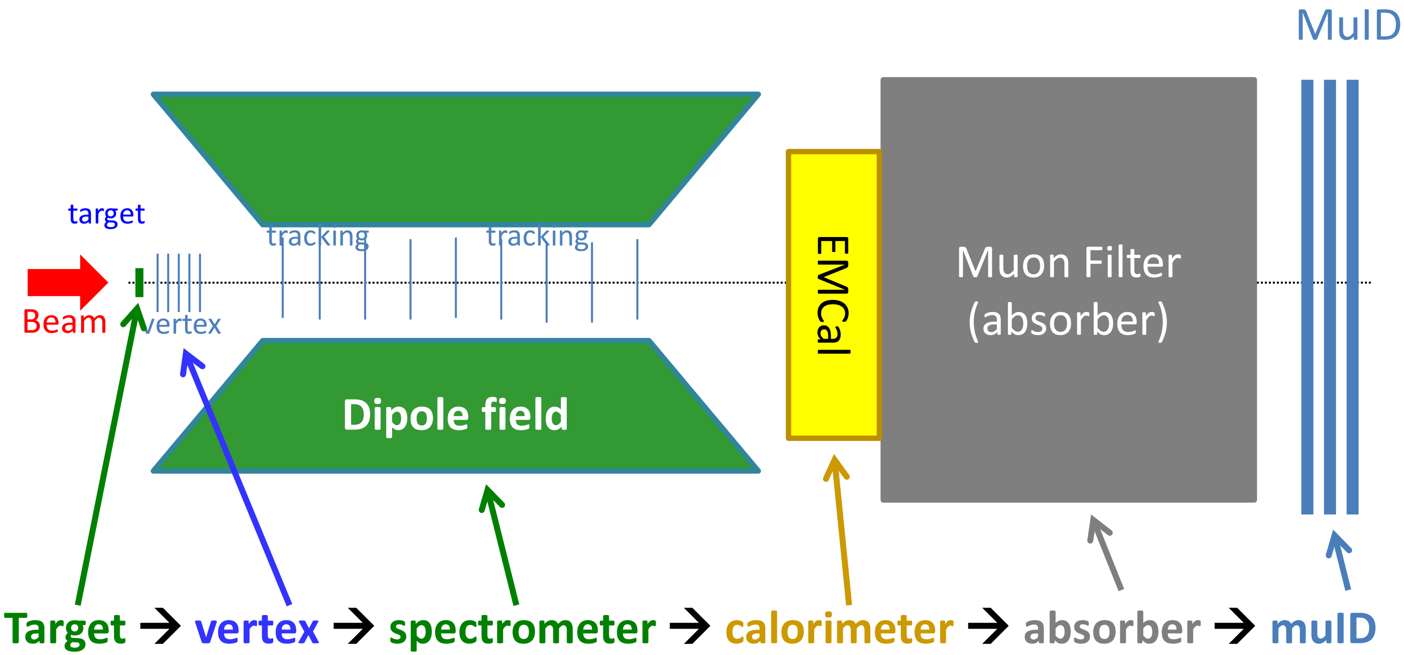
- **Experimental constraints**
  - kinematics
    - **CHIC**: Access $y_{cms} \in [-0.5, 2]$
    - **AFTER**: access $y_{cms} \in [-3.5, 0]$
  - Beams
    - p+p, p+A, A+A
  - Detector
    - **CHIC**: vertexing, tracking, calorimetry, muon ID
    - **AFTER**: vertexing, tracking, calorimetry, muon ID, PID

CHIC ≡ demonstrator for AFTER



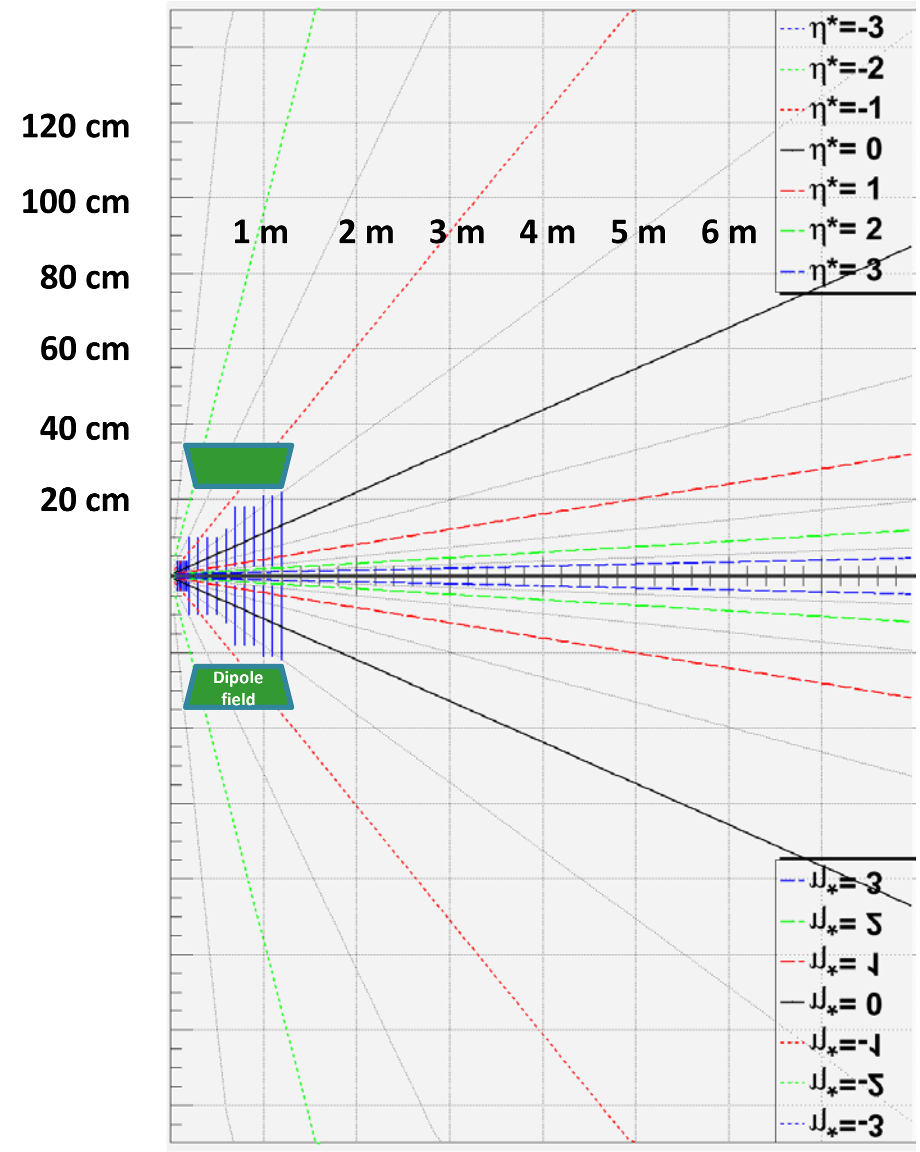


- **design generalities (Common to CHIC/AFTER)**
  - Adopt particle physics strategy
  - Measure dimuons and **photons**
    - Must place the **calorimeter in front of the absorber**
    - Must separate photon/electron → **tracking in front of the calorimeter**.



Detector design

tracking



Vertex detector :

R_{min} = 0.5 cm Z_{min} = 7.5 cm
R_{max} = 3.5 cm Z_{max} = 18 cm

Spectrometer :

R_{min} = 1 cm Z_{min} = 20 (100) cm
R_{max} = 22 cm Z_{max} = 120 (200) cm

Magnet:

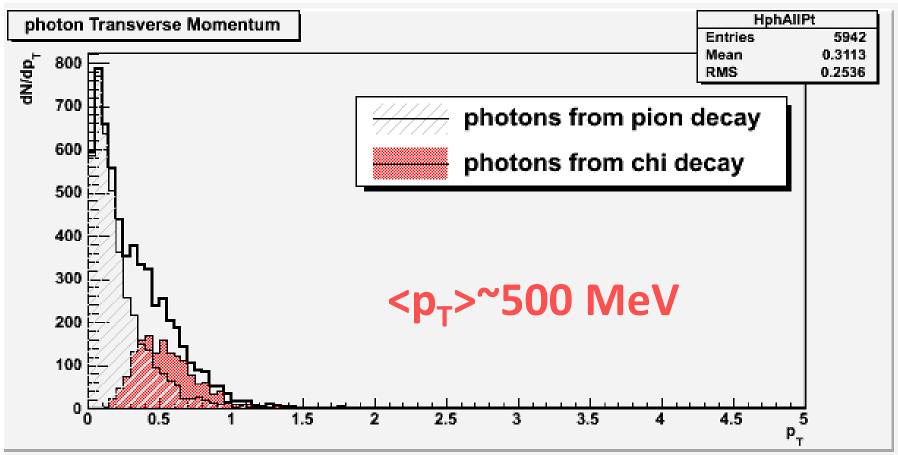
Typical J/Ψ P_μ ~ 15 GeV
➔ With a 1 m long 2.5 T dipole:

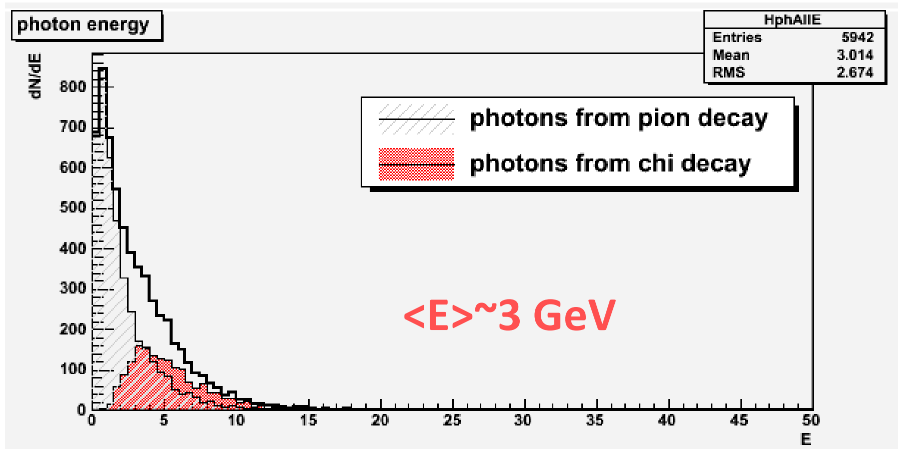
$$\frac{\Delta P}{P} = 1\% \Rightarrow \Delta M_{J/\Psi} \sim 20\ \text{MeV}$$

Detector design calorimetry

- **Goal : measure $\chi_c \rightarrow J/\Psi + \gamma$**
- **Issues**
  1. Low energy photon (similar to $\pi^0 \rightarrow \gamma\gamma$)
  2. High multiplicity of photon from $\pi^0 / \eta \rightarrow \gamma\gamma$
  3. High multiplicity of charged particles ($\pi^{+/-}$)

Pythia 6.421 - p+p - $\sqrt{s}$ = 17.2 GeV





Detector design — calorimetry

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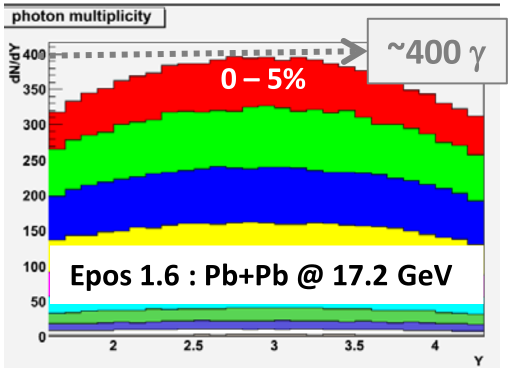
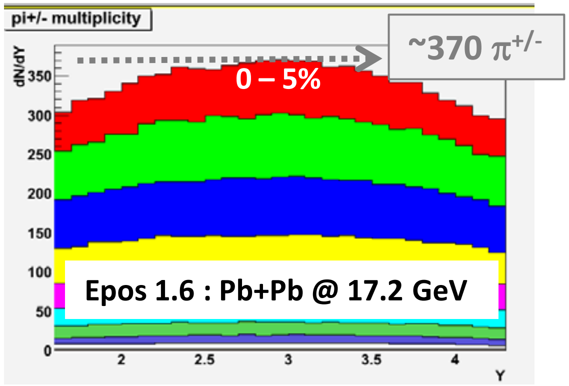
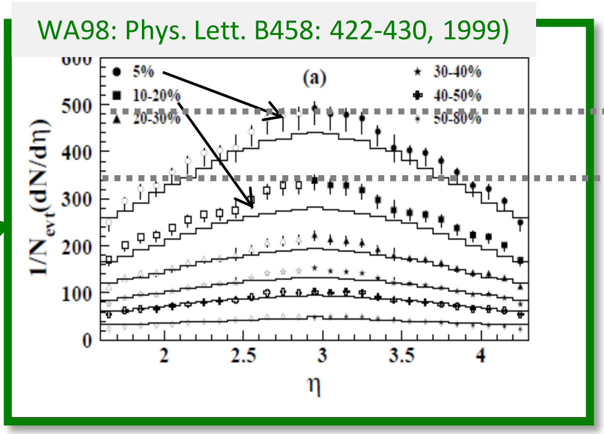
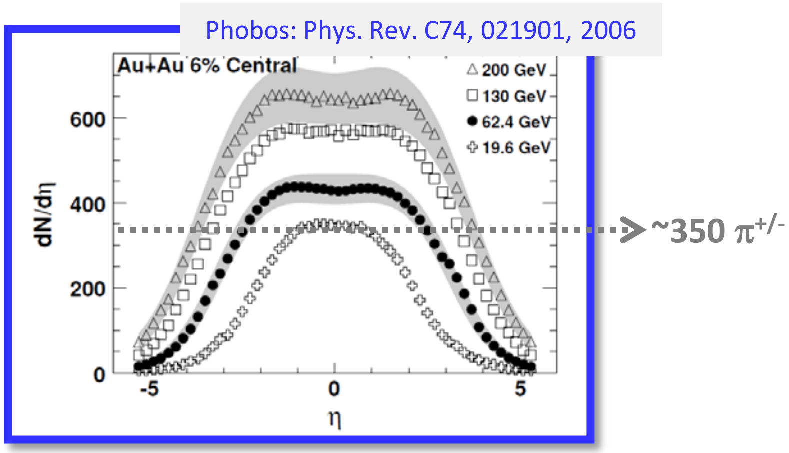




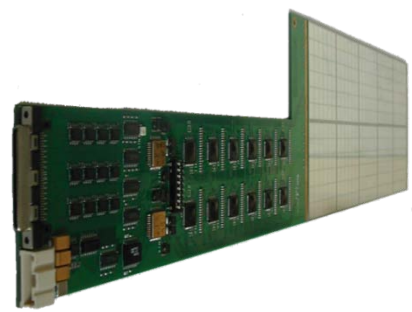


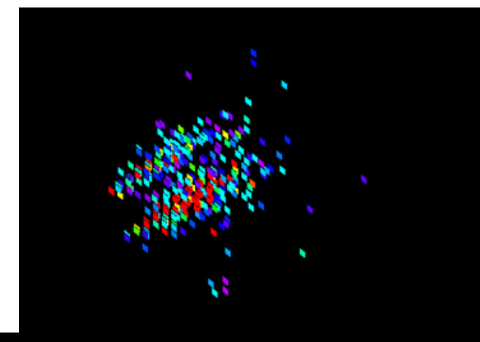


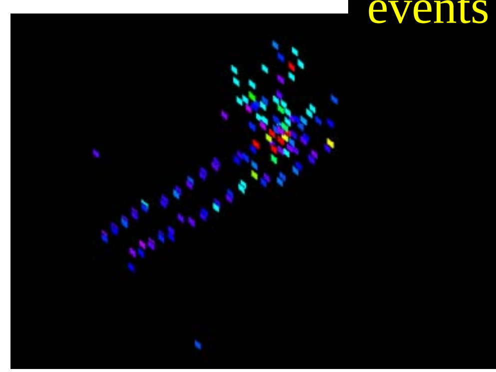
0 – 5% Pb+Pb most central → ~450 γ + 350 $\pi^{+/-}$
(we don't need to go that central for χ_c)

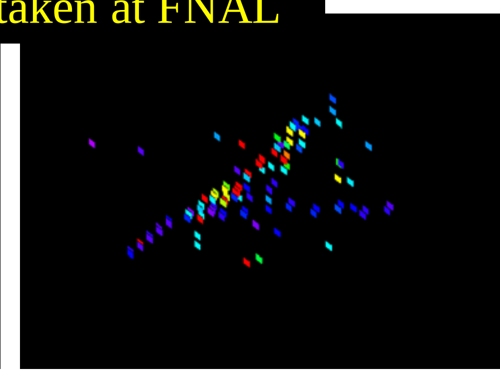
Detector design — calorimetry

- **Need very high segmentation**
  - to separate two electromagnetic showers
  - To isolate photons from $\pi^{+/-}$ contamination
- **W + Si calorimeter à la Calice**
  - 30 layers
  - 0.5 x 0.5 cm^2 pads
  - 24 X_0 in 20 cm
- **LLR – Contributions**
  - Mechanics
  - Sensors
  - DAQ
  - Reconstruction (GARLIC)
  - Simulation (MOKKA)









events taken at FNAL

Detector design — calorimetry

- **Need very high segmentation**
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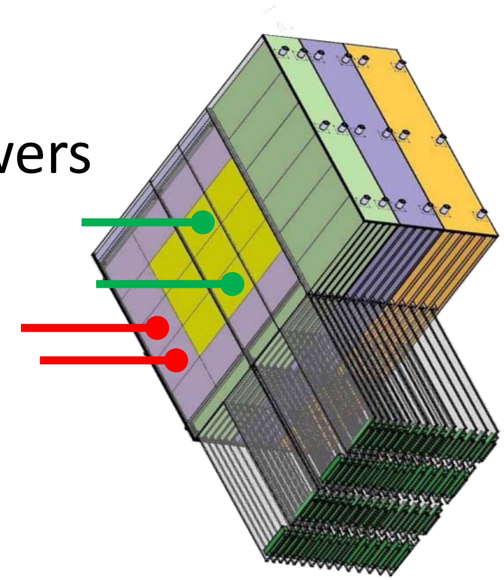
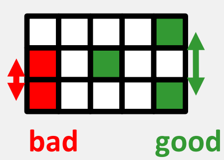


1st relevant quantity : distance between two incoming particles



→Min. distance between 2 particles at impact = 1 free pad = 1 cm (for 0.5×0.5 cm²)

→distance between two incoming particles must be > 1 cm

→N photons ➔ N/2 neutrals (π^0 + η)➔ N $\pi^{+/-}$ ➔ N γ + N $\pi^{+/-}$ = 2N particles

→ distance between two photons must be > 2 cm (1cm×2N/N)

2nd relevant quantity : EM shower transverse size
→Moliere Radius R_M : 90% of the shower energy

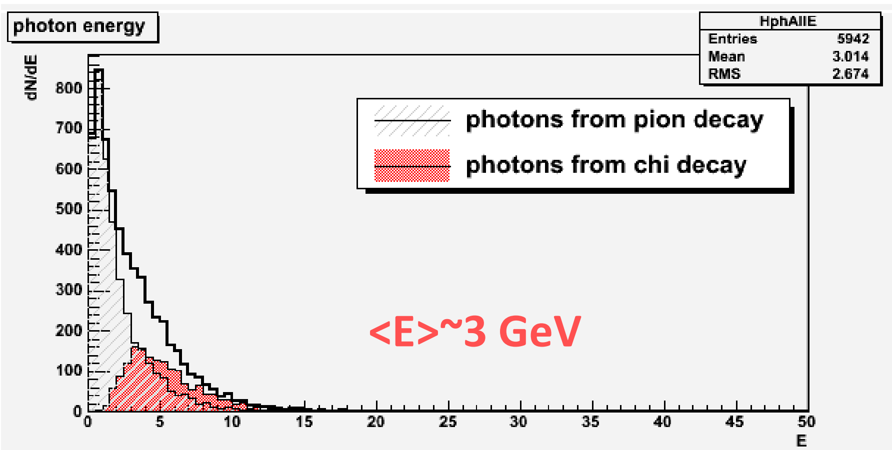
$$\begin{cases} R_M = X_0 \dfrac{21\,\mathrm{MeV}}{610\,\mathrm{MeV}/(Z+1.24)} \\ X_0 = \dfrac{716.4 \times A\ \mathrm{g.cm^{-2}}}{Z(Z+1)\ln\left(287/\sqrt{Z}\right)} \end{cases} \Rightarrow R_M(W) = \frac{17.6\,\mathrm{g.cm^{-2}}}{19.25\,\mathrm{g.cm^{-3}}} \approx 0.9\,\mathrm{cm}$$

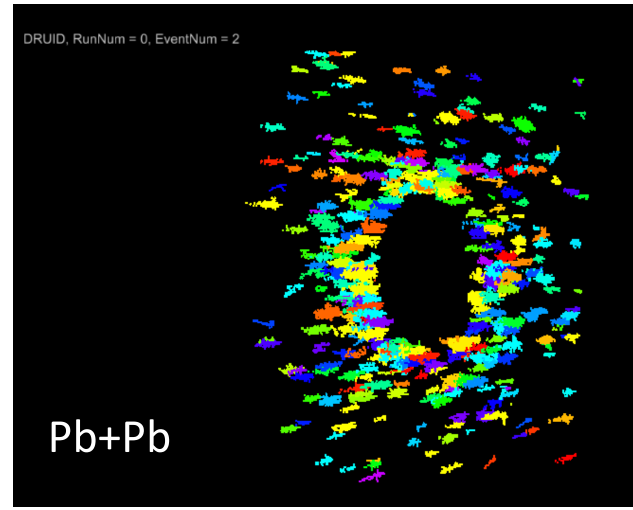
→Distance between two photons must be > 2 cm (2 R_M)

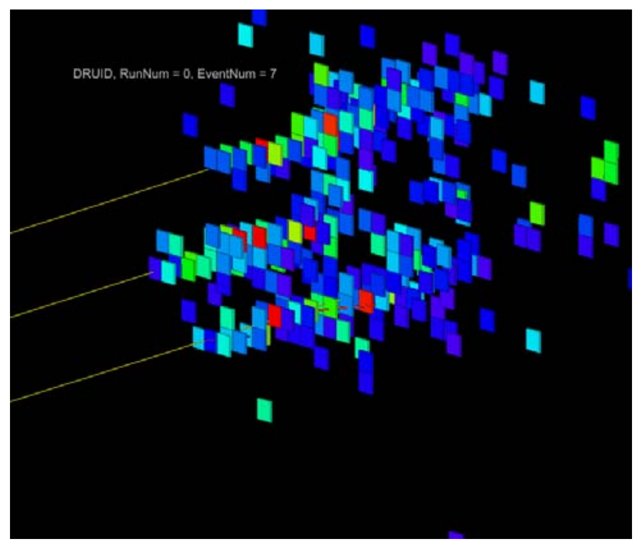
Geometrical condition: in principle $\Delta\gamma$ > 2cm

Detector design calorimetry

- **Full simulation performed with the Calice Ecal proto**





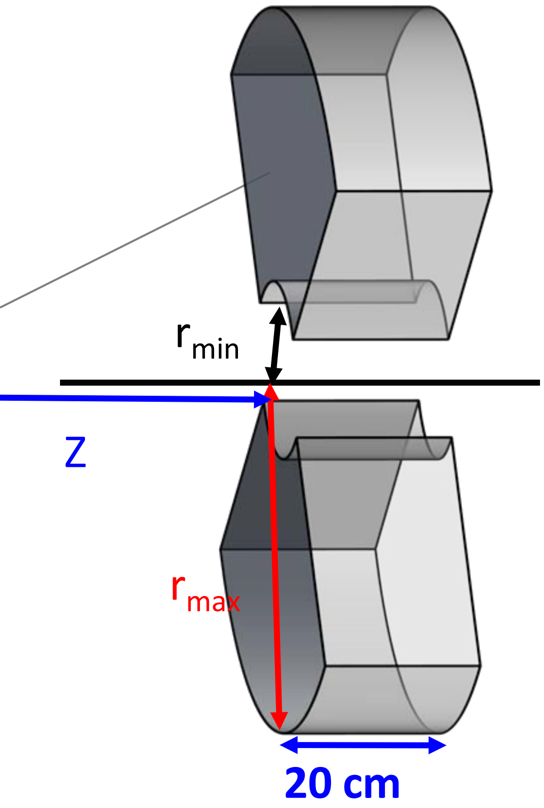


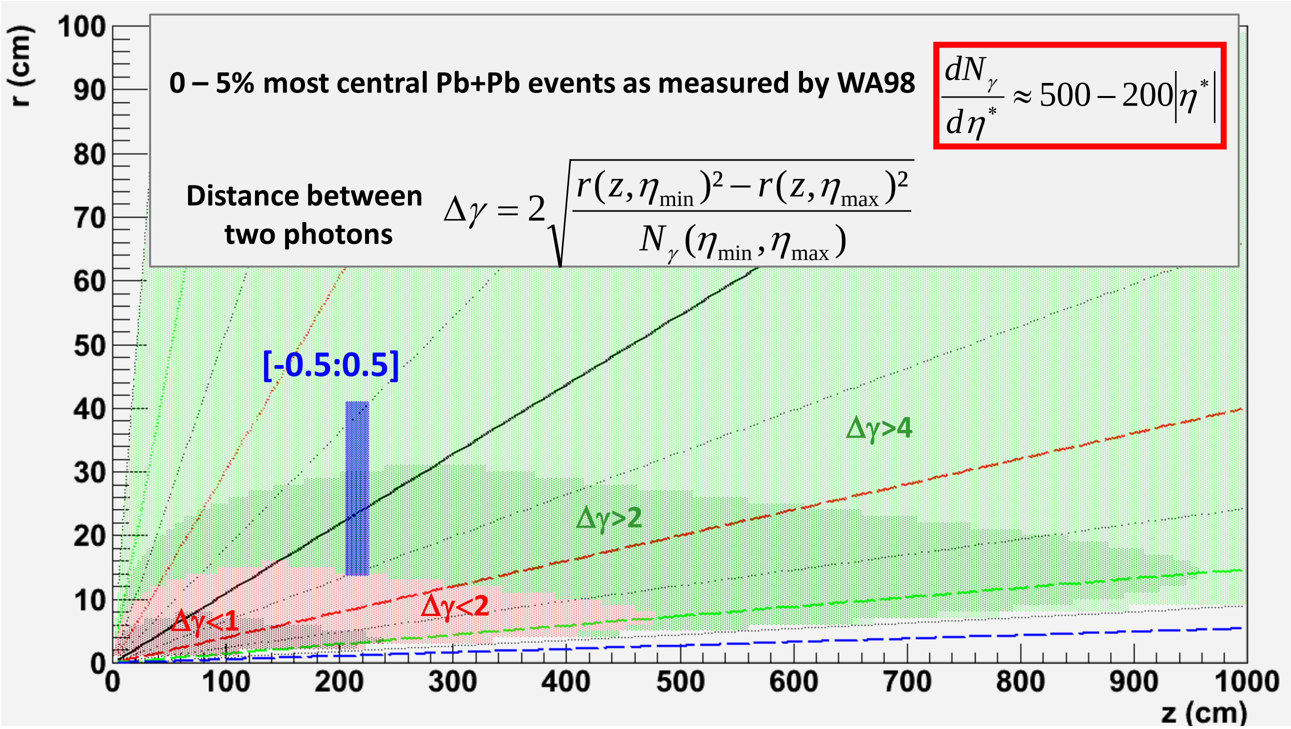
3 photons with E~2 GeV
distance between each photon~ 2 cm

0.5 x 0.5 cm² pads

(full simu made by D. Jeans - Calice collab.)

- **Size and position : tentative design**





Closer position to the target w/ **Δγ>2cm**:

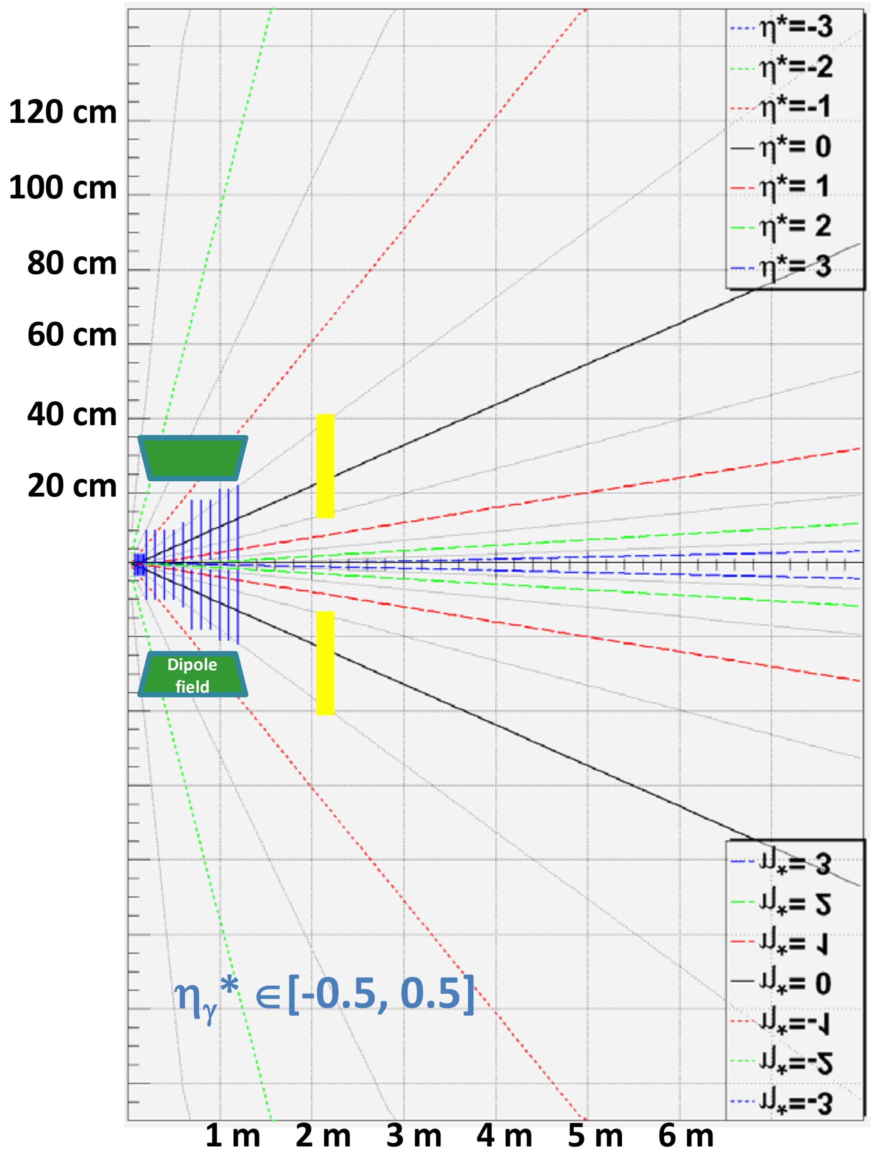
➔Z = 205 cm [-0.5:0.5]

➔R_{min} = 13.6 cm

➔R_{max} = 40.9 cm

Using 0.5 x 0.5 cm² pads

Detector design Overview



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Spectrometer :

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R_{max} = 22 cm Z_{max} = 120 (200) cm

Calorimeter $\Delta\gamma$>2 cm:

Rmin = 14 cm Zmin = 205 cm

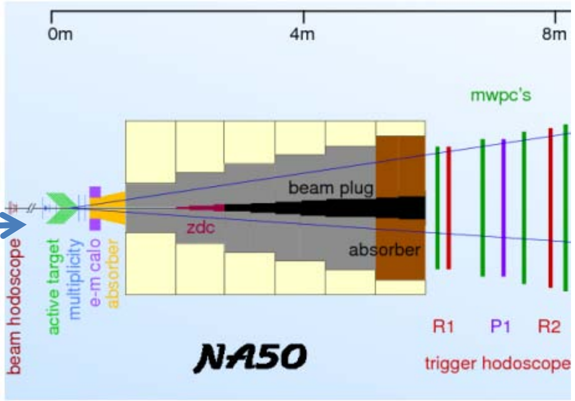
Rmax = 41 cm Zmax = 225 cm

- **Absorber type**

NA50/NA60 : measure muon momentum **after** the absorber

➔ **must minimize multiple scattering**

- Must use low Z material: best = BeO (but expensive)
- **NA50 : 0.6 m BeO + 4 m C + 0.6 m Fe = 5.2 m**

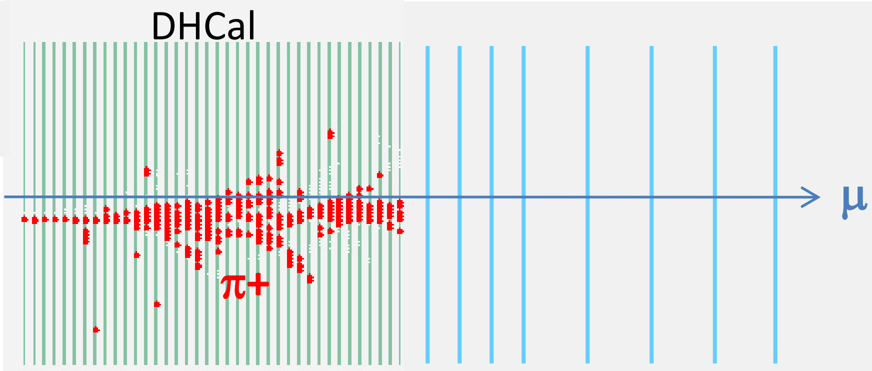


CHIC : measure muon momentum before the absorber

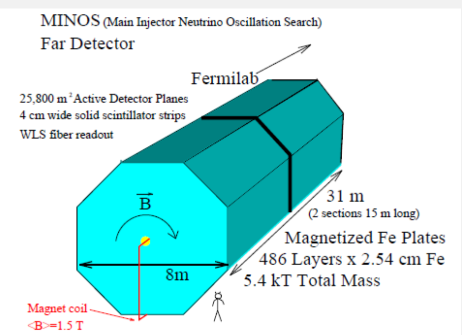
➔ minimization of multiple scattering not crucial

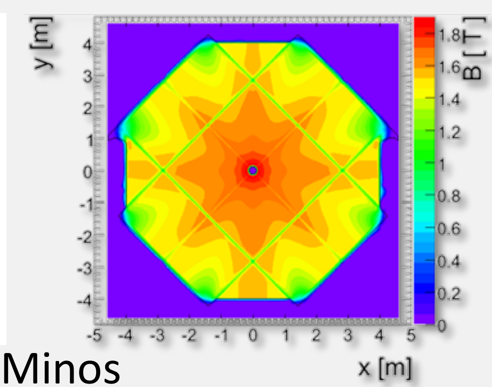
➔ **can use Fe material To absorb $\pi^{+/-}$**

Need to **match muon track position** between spectrometer and trigger : **Use an instrumented Fe absorber**



http://newsline.linearcollider.org/archive/2010/20101104.html



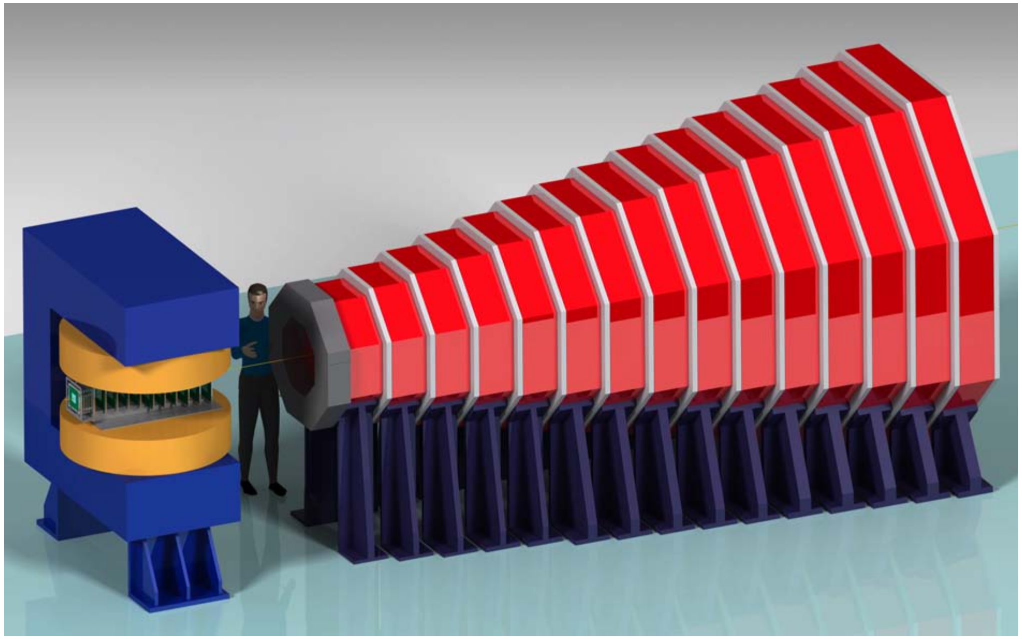


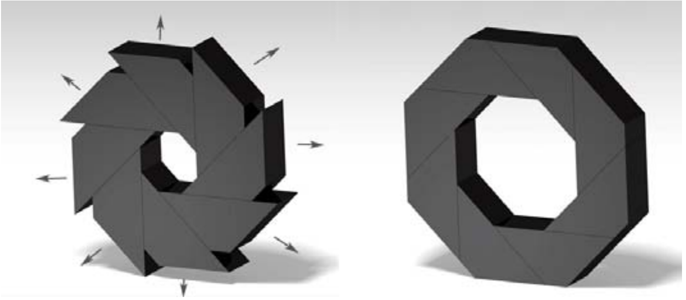
Minos

Can match muon track momentum between spectrometer and trigger : **Use magnetized Fe absorber ?**

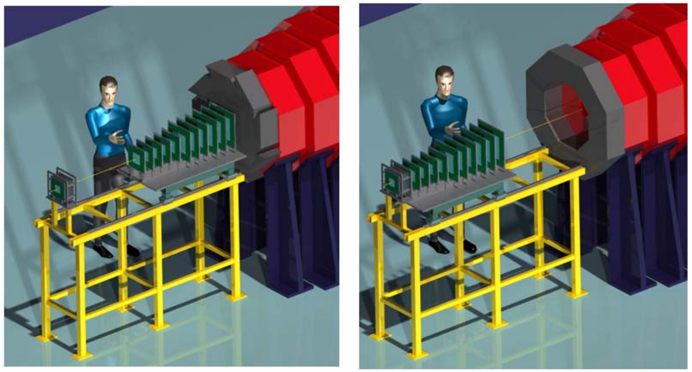
- **CHIC: Experimental setup flexibility**

Very compact detector
(full detector simulation ongoing) ➡



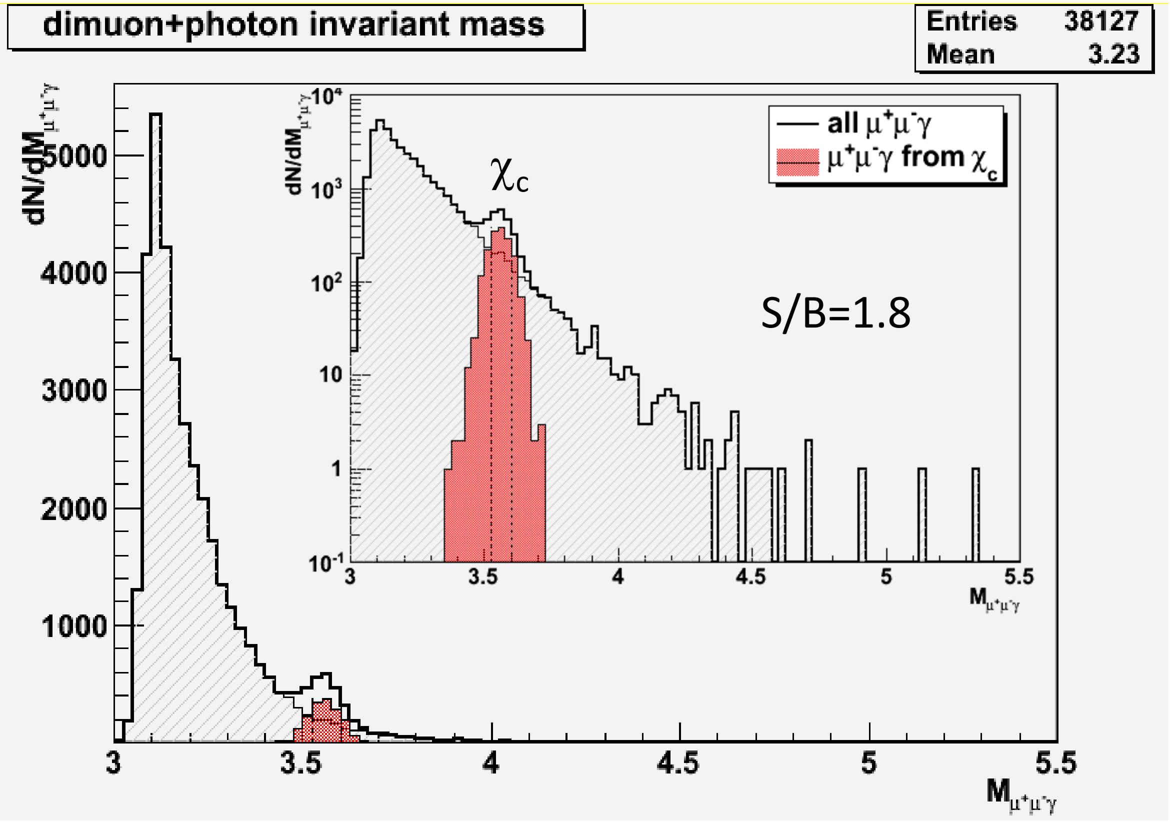


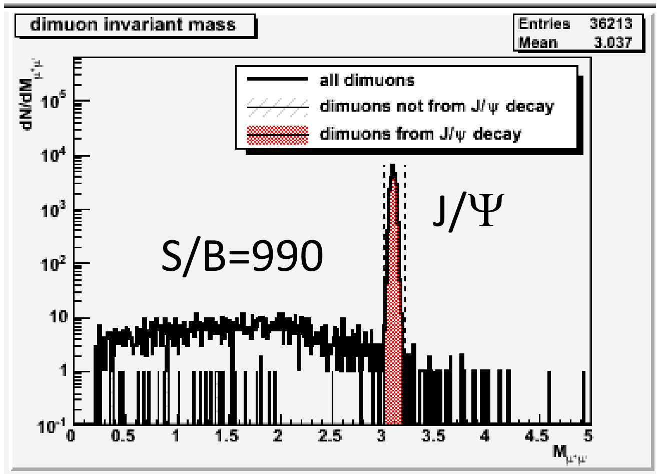
Forward rapidity **Mid rapidity**



Large rapidity coverage
- fixed target mode → high flexibility
- displace tracker to access large rapidity
- modify calorimeter to access large rapidity

- **Typical mass plots**
  - 200 000 Pb+Pb minBias EPOS events
    - 140 000 events with J/Ψ embedded (70%)
    - 60 000 events with χ_c embedded (30%)





After acceptance and selection cuts:

- 35 000 **J/Ψ**
  ➔ **acc x eff = 17.4%**
- 1700 χ_c
  ➔ **acc x eff = 2.8 %**

Figure of Merit

- **Typical one month Pb+Pb run with a 4mm thick target**
  - ~ 200 000 inclusive $J/\Psi \rightarrow \mu^+\mu^-$ expected
  - 2 extreme scenarios:
    - If χ_c suppressed as J/Ψ $\quad \frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

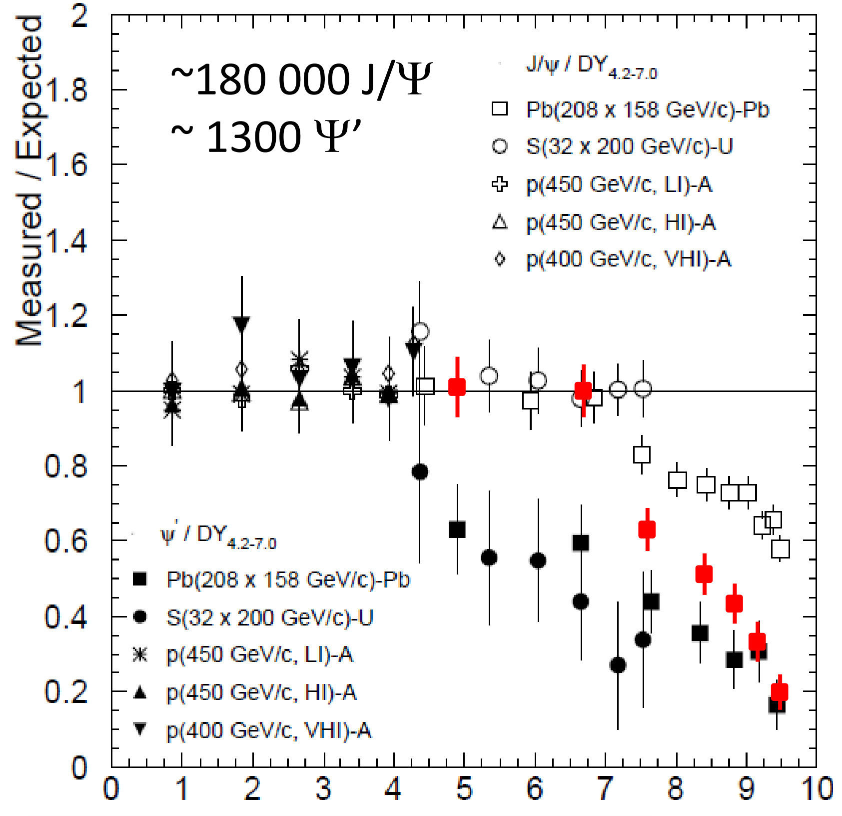
$$\Rightarrow \begin{pmatrix} \text{most periph.} \\ \chi_c \text{ yield} \end{pmatrix} = 16942 \times 4\% = 677$$

    - If χ_c suppressed as Ψ' $\quad \frac{\chi_c \text{ yield}}{\Psi' \text{ yield}} = 2.18$

$$\begin{pmatrix} \text{most periph.} \\ \chi_c \text{ yield} \end{pmatrix} = 16942 \times 4\% \times 0.6 = 406$$

E_T range (GeV)	ψ'	J/ψ	χ_c as J/Ψ	χ_c as Ψ'
3–20	186 ± 25	16942 ± 146	677	406
20–35	243 ± 31	25229 ± 181	1010	530
35–50	227 ± 35	27276 ± 192	1091	495
50–65	193 ± 36	27681 ± 196	1107	421
65–80	154 ± 36	27315 ± 200	1093	336
80–95	159 ± 37	25111 ± 193	1004	347
95–150	110 ± 40	28570 ± 209	1143	240
			7125	**2775**

Eur.Phys.J.C49:559-567,2007



Uncertainties

χ_c stat > 2 x Ψ' stat

➔ χ_c error < Ψ' error/$\sqrt{2}$

Conclusion

- **CHIC at SPS : current status**
  - No show stopper for measurement of χ_c in Pb+Pb at SPS
  - Towards writing a Letter (contributions are very welcome)
  - Activities : currently starting a simulation with Geant4 ; support of 1 computer engineer and 1 Calice postdoc at LLR
- **From CHIC to AFTER**
  - After will be a large/expensive detector using detector technologies which have been developed for other physics subjects ; a demonstrator would be very welcome
  - CHIC
    - It is a smaller scale than AFTER
    - Beam is available
  - CHIC could be a perfect demonstrator for AFTER