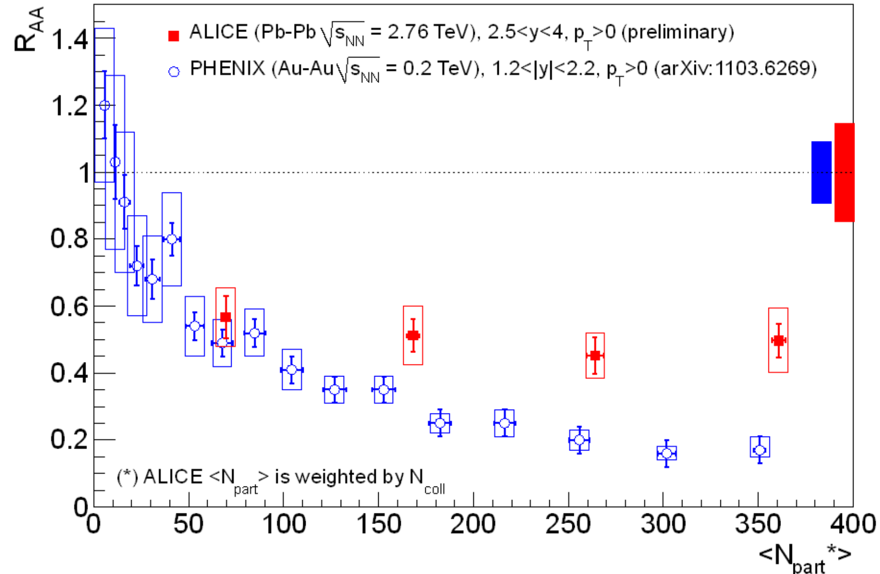
CHIC

Charm in Heavy Ion Collisions @ SPS

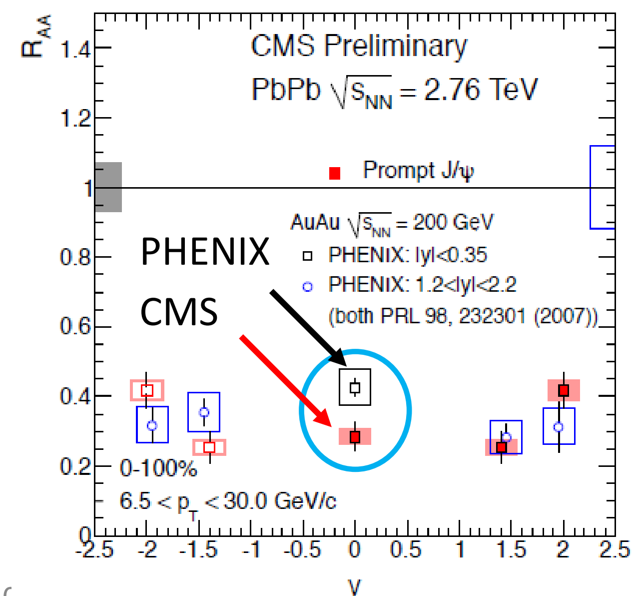
1. J/Ψ – Suppression in A+A
2. CHIC – Physics motivations
3. CHIC – Experimental aspects

J/Ψ – Suppression in A+A

- **RHIC (200 GeV) .vs. LHC (2.76 TeV) at forward rapidity**
  - Compare PHENIX vs ALICE
    - 1.2 < |*y*| < 2.2 at RHIC **(PHENIX)**
    - 2.5 < *y* < 4 at LHC **(ALICE)**
  - **LESS SUPPRESSION** at LHC .vs. RHIC
  - Could be due to **recombination** effects



- **RHIC (200 GeV) .vs. LHC (2.76 TeV) at mid-rapidity**
  - Compare PHENIX vs CMS
    - |y|<0.35 at RHIC **(PHENIX)**
    - |y|<1 at LHC **(CMS)**
  - **MORE SUPPRESSION** at LHC .vs. RHIC
    - p_T>6.5 GeV/c ➔ in principle no recombination applies
    - larger suppression due to **QGP effects ?**
  - Hint for **sequential suppression ? (J/Ψ melting)**



Caution : Need CNM effects comparison

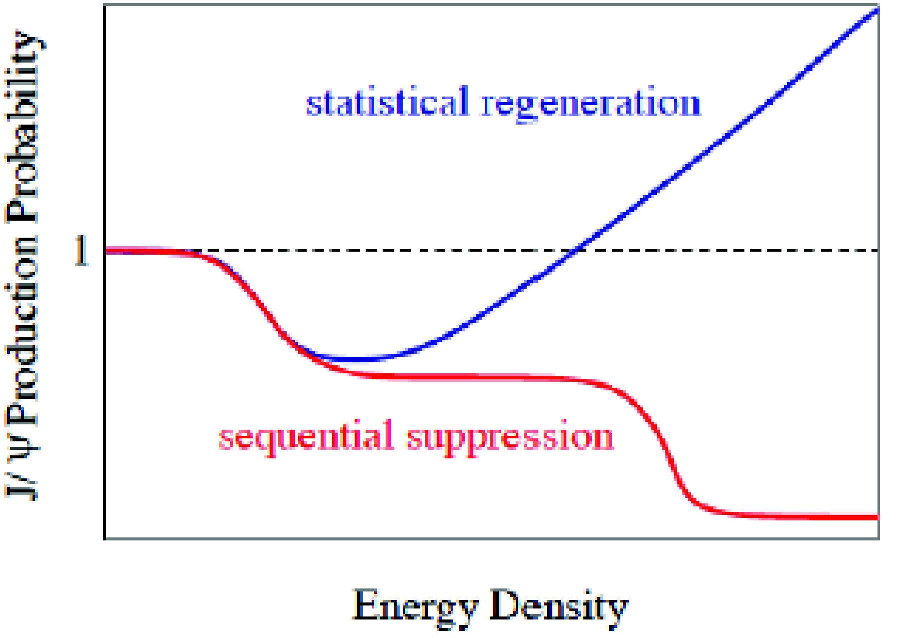
J/Ψ – Suppression in A+A

- **Overall (simplified) picture**

1. **Similar suppression at SPS.vs.RHIC**

2. **Larger suppression at LHC outside recombination regime**
   CMS results
   Hint of sequential suppression ?
   (assuming CNM effects are the same or smaller)

3. **Smaller suppression at LHC inside recombination regime**
   ALICE results
   Hint of recombination?
   (assuming CNM effects are the same of larger)



- **To do:**
  – Understand CNM effects : p+Pb run
  – Test recombination mechanism : J/Ψ at mid-rapidity at low p_T
  – Test sequential suppression → measure χ_c in A+A→ not accessible → **CHIC experiment**

CHIC – Physics motivations

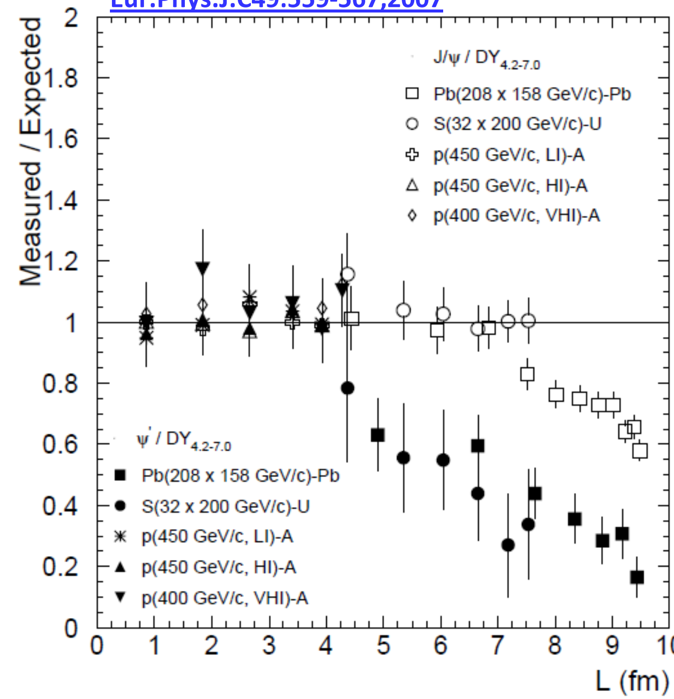
1. Benchmark: Measure χ_c in A+A at SPS

How χ_c is suppressed relative to J/Ψ ?
What is the dependence with y, p_T, centrality,… ?
Mandatory to draw the whole picture (SPS .vs. RHIC .vs. LHC)

Why SPS ?

1. **First place where anomalous suppression has been seen.**
2. **SPS good place to see full Sequential suppression : Ψ', J/Ψ, χ_c**
3. **No recombination at SPS**

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



CHIC – Physics motivations

- **Quarkonia suppression**

At SPS

60% direct J/Ψ
+ 30% $\chi_c \rightarrow J/\Psi + \gamma$
+ 10% $\Psi' \rightarrow J/\Psi + X$

Inclusive J/Ψ yield

Two possible scenarios:

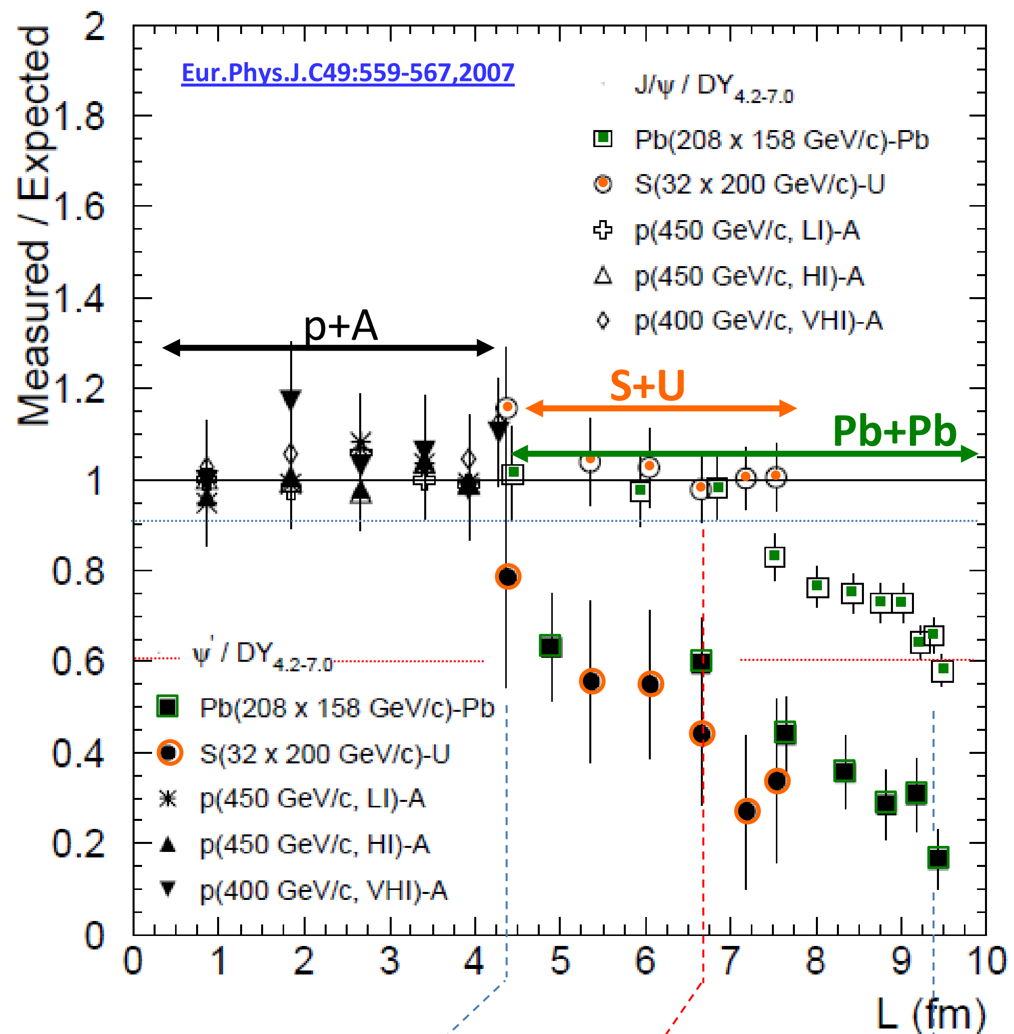
- **sequential suppression (QGP)**
- **comovers (no QGP)**

Temperature of dissociation

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

Binding energy

state	η_c	J/ψ	χ_{c0}	χ_{c1}	χ_{c2}	ψ'
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69
ΔE [GeV]	0.75	0.64	0.32	0.22	0.18	0.05



L (fm)	4.37	4.90	6.65	7.65	8.83	9.43
ε (GeV/fm³)	1.04	1.24	2.04	2.53	3.19	3.76

CHIC – Physics motivations

- **Two possible scenarios**

1. QGP (sequential suppression)

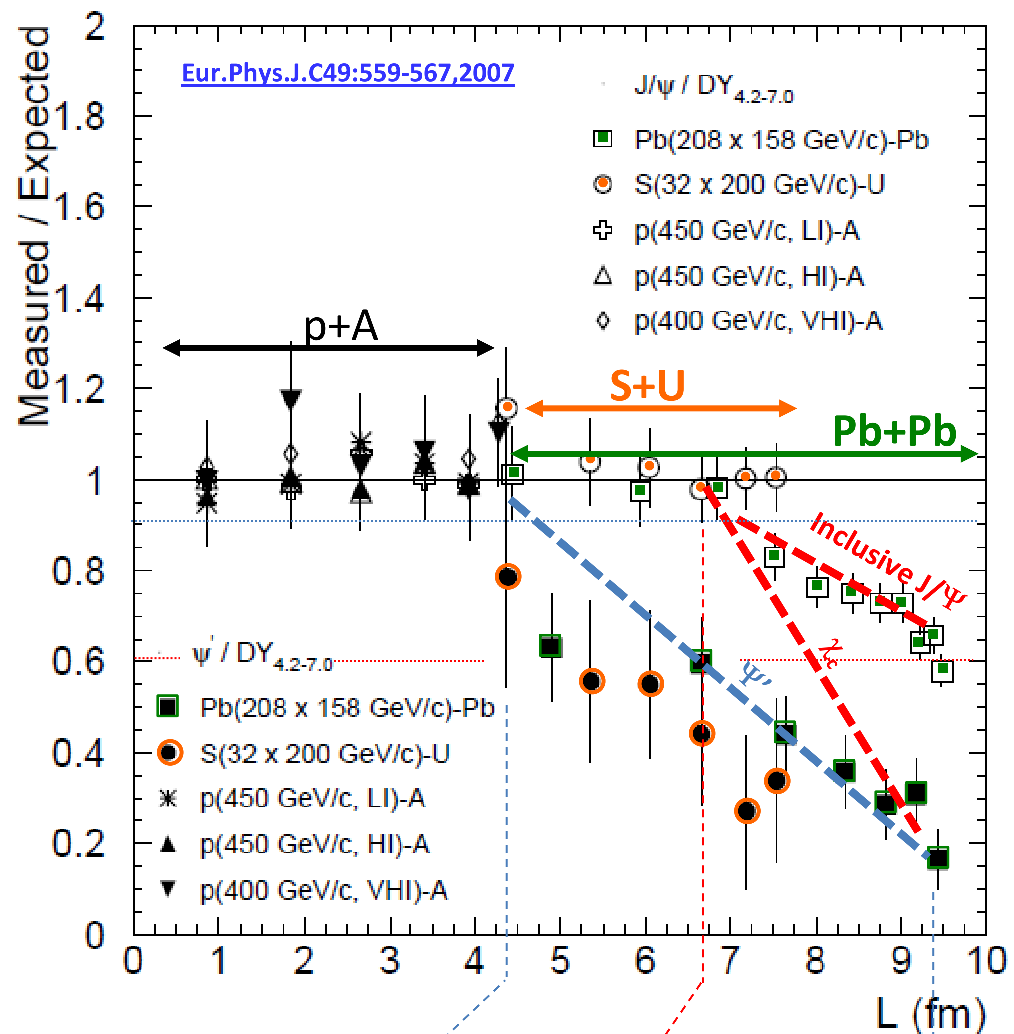
state	η_c	J/ψ	χ_{c0}	χ_{c1}	χ_{c2}	ψ'
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69
ΔE [GeV]	0.75	0.64	0.32	0.22	0.18	0.05

Because ΔE (Ψ') ~50 MeV
- **Ψ' easily suppressed by comovers**

Because $\Delta E(\chi_c)$~200 MeV and $\Delta E(J/\Psi)$~600 MeV
- **χ_c and J/Ψ hardly suppressed by comovers**

If χ_c suppressed by **QGP**,
- **χ_c slope strongly steeper than J/Ψ and Ψ'**

Measuring
χ_c suppression pattern will (in)validate this



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Note that direct J/Ψ can be experimentally estimated

$$\text{Yield}_{\text{incl.}J/\Psi} - \text{Yield}_{\chi c \rightarrow J/\Psi+\gamma} - \text{Yield}_{\Psi'} \sim \text{Yield}_{\text{direct } J/\Psi}$$

CHIC – Physics motivations

- **Two possible scenarios**

2. No QGP (full comovers)

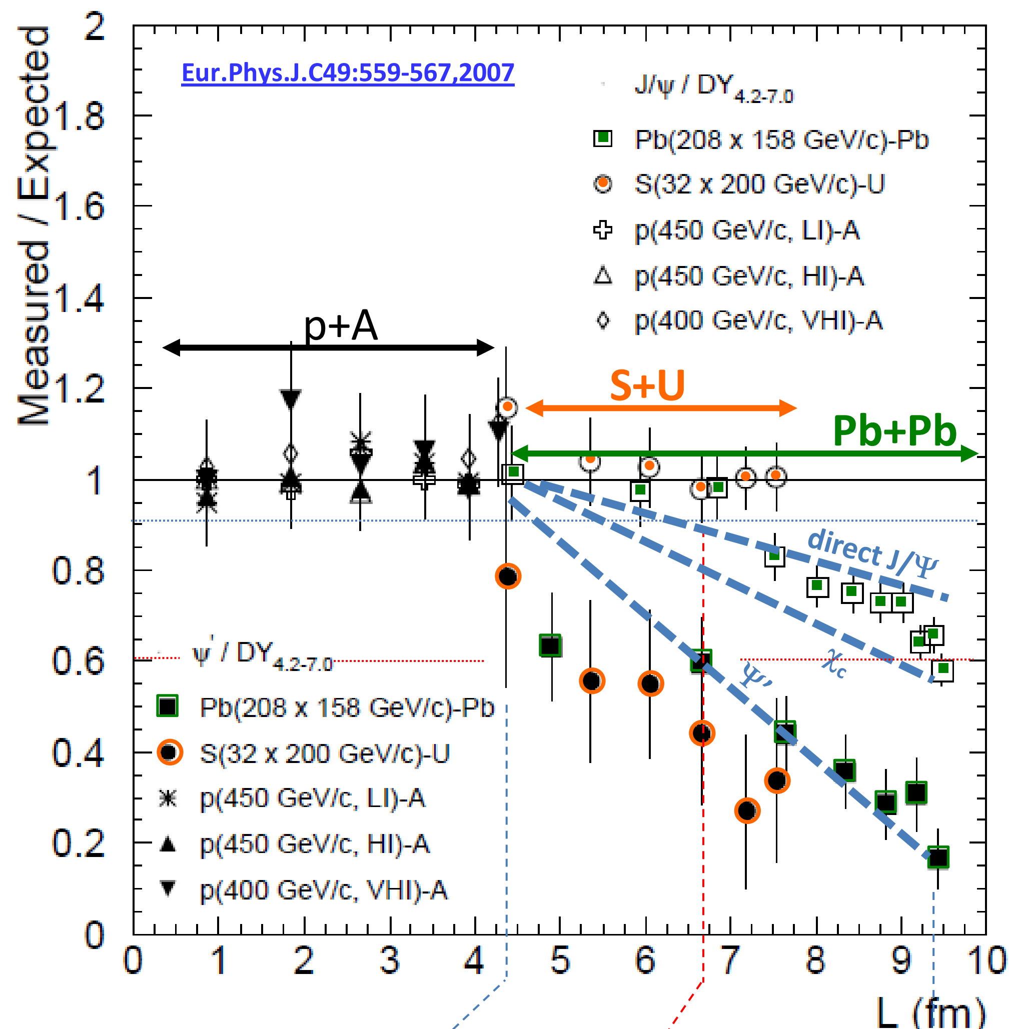
state	η_c	J/ψ	χ_{c0}	χ_{c1}	χ_{c2}	ψ'
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69
ΔE [GeV]	0.75	0.64	0.32	0.22	0.18	0.05

Because $\sigma_{J/\Psi\text{-co}} \leq \sigma_{\chi c\text{-co}} \leq \sigma_{\Psi'\text{-co}}$

- Ψ' slope slightly steeper than χ_c
- χ_c slope slightly steeper than J/Ψ

Measuring

χ_c suppression pattern will (in)validate this



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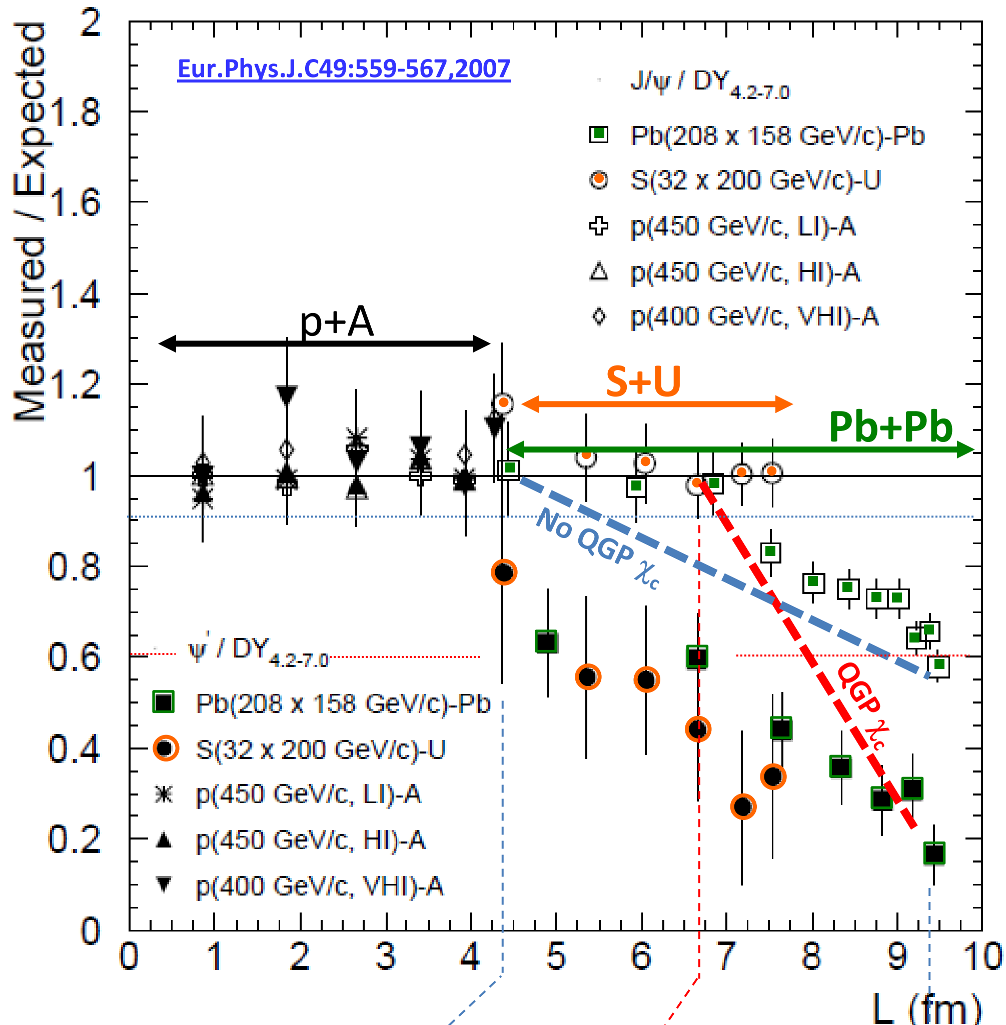
CHIC – Physics motivations

- **Conclusion : measure χ_c in A+A at SPS**

measuring
Ψ', J/Ψ and χ_c suppression pattern

will answer the question

------ QGP
------ no QGP



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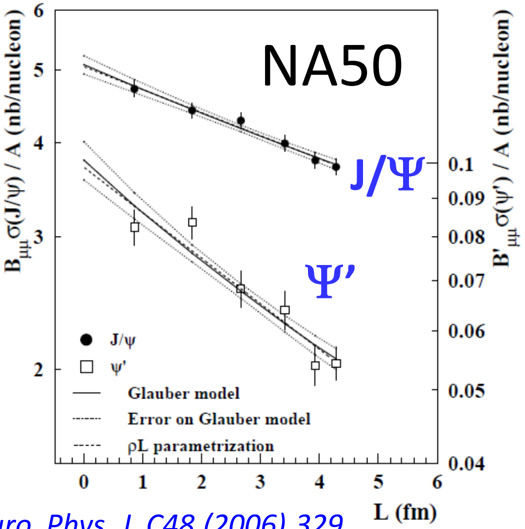
CHIC – Physics motivations

2. Benchmark: Measure charmonium in p+A at SPS

J/Ψ and Ψ' **suppression** in p+A collisions as a function of L

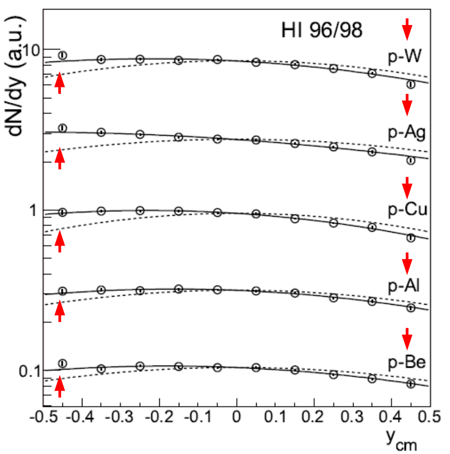
➔ **Measuring different charmonium states gives key information on Cold Nuclear Matter and production mechanism.**



Euro. Phys. J. C48 (2006) 329.

J/Ψ **rapidity distribution** in p+A collisions (asymetry wrt y_{cm}=0)

➔ **Measuring charmonium in a wide x_F range is important to identify possible (anti)shadowing effects**



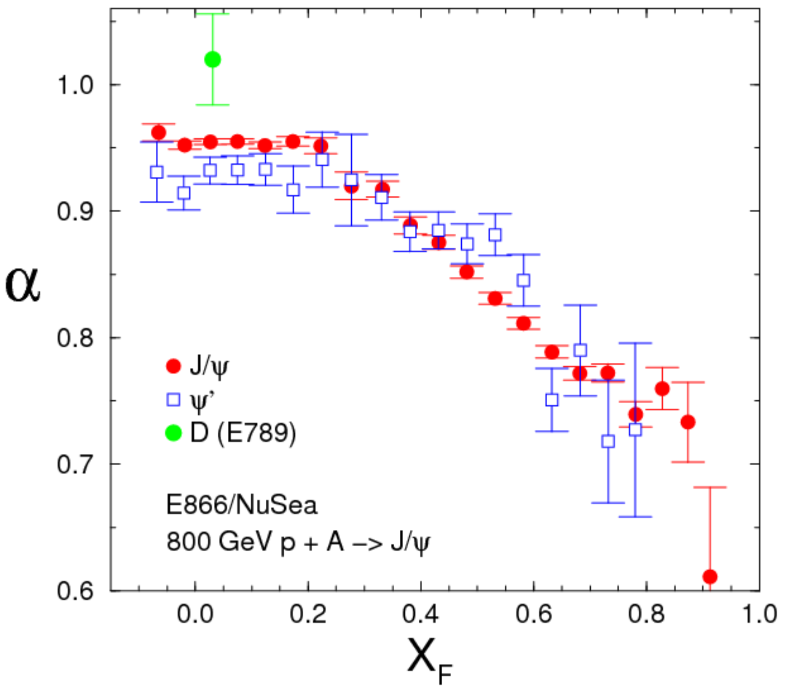
CHIC – Physics motivations

2. Measure charmonium in p+A at SPS

➔ Measuring charmonium in a wide x_F range is important to estimate possible (anti)shadowing effects

$$\sigma_A = \sigma_p * A^\alpha$$

E866, Phys. Rev. Lett. 84, 3256-3260 (2000)



$$x_F = \frac{2M}{\sqrt{s}} \sinh y_{CMS}$$

With M=3.1 GeV/c² and **√s=17.2 GeV** (158 GeV)
$x_F = 1$ ➔ $y_{CMS} = 1.7$

With M=3.1 GeV/c² and **√s=29.1 GeV** (450 GeV)
$x_F = 1$ ➔ $y_{CMS} = 2.2$
$Y_{CMS}=2$ ➔ $x_F = 0.8$

Possible to access large x_F if measuring charmonia at rapidity up to y_{CMS}~2

CHIC – Physics motivations

1. Measure χ_c production in A+A

How χ_c is suppressed relative to J/Ψ ? What is the dependence with y, p_T, N_{part},… ?

Mandatory to draw the whole picture (SPS .vs. RHIC .vs. LHC)

Benchmark 1 : Measure χ_c production within $y_{CMS} \in [-0.5, 0.5]$

2. Measure charmonia production in p+A

what is the dependence of charmonia suppression with rapidity ?

Crucial to understand effects due to cold nuclear matter

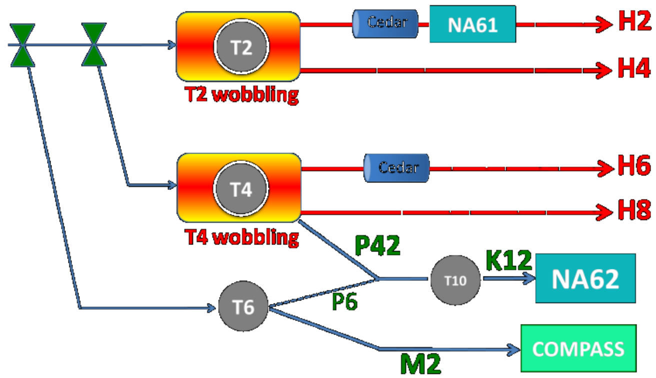
Benchmark 2 : Measure charmonium states within $y_{CMS} \in [-0.5, 2]$

3. Other physics subjects

Open charm, low mass resonances, Drell-Yan,…

CHIC – Expected yields

North Area Beamlines

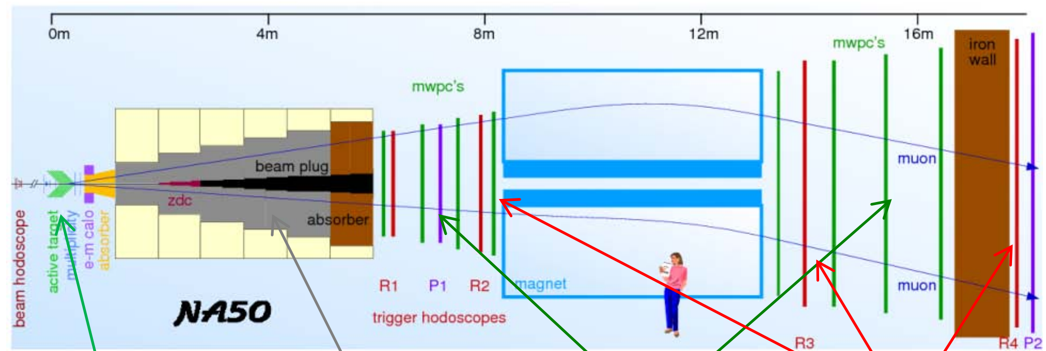


- Need high intensity p and Pb beams (~ 10^7 Pb/sec)
  - NA50/NA60 beam line not available (NA62)
  - H2 beam line occupied by NA61
  - H4 and H8 available but need shielding for HI
- NA50: European Physical Journal C39 (2005) 335
  - *New measurement of J/ψ suppression in Pb+Pb at 158 GeV/nucleon*
  - 35 days of data taking in 2000
  - ~1.10^7Pb/s over 5s bursts every 20s
  - 4 mm thick Pb target (10%λ_I)
  - ~ 100 000 $J/\Psi \rightarrow \mu^+\mu^-$ within $y^* \in [0,1]$ (on disk)
- Expect fair amount of χ_c: **$N_{J/\Psi}$ ~ 60% direct + ~30% from χ_c + ~10% from Ψ'**
  - Same conditions as NA50 setup → **~20 000 χ_c expected within $y_{CMS} \in [-0.5,0.5]$**
  - Expect more with thicker target (1cm for instance)

CHIC – detector design

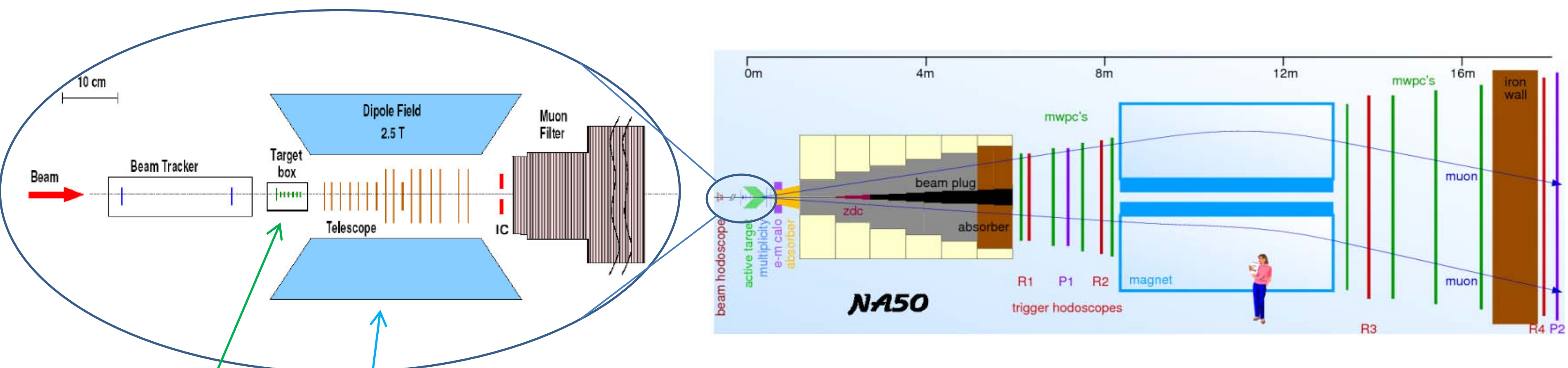
- **Past experiments**

1st generation: NA38,NA50,NA51
Measure dimuons



Target → absorber → spectrometer → muID

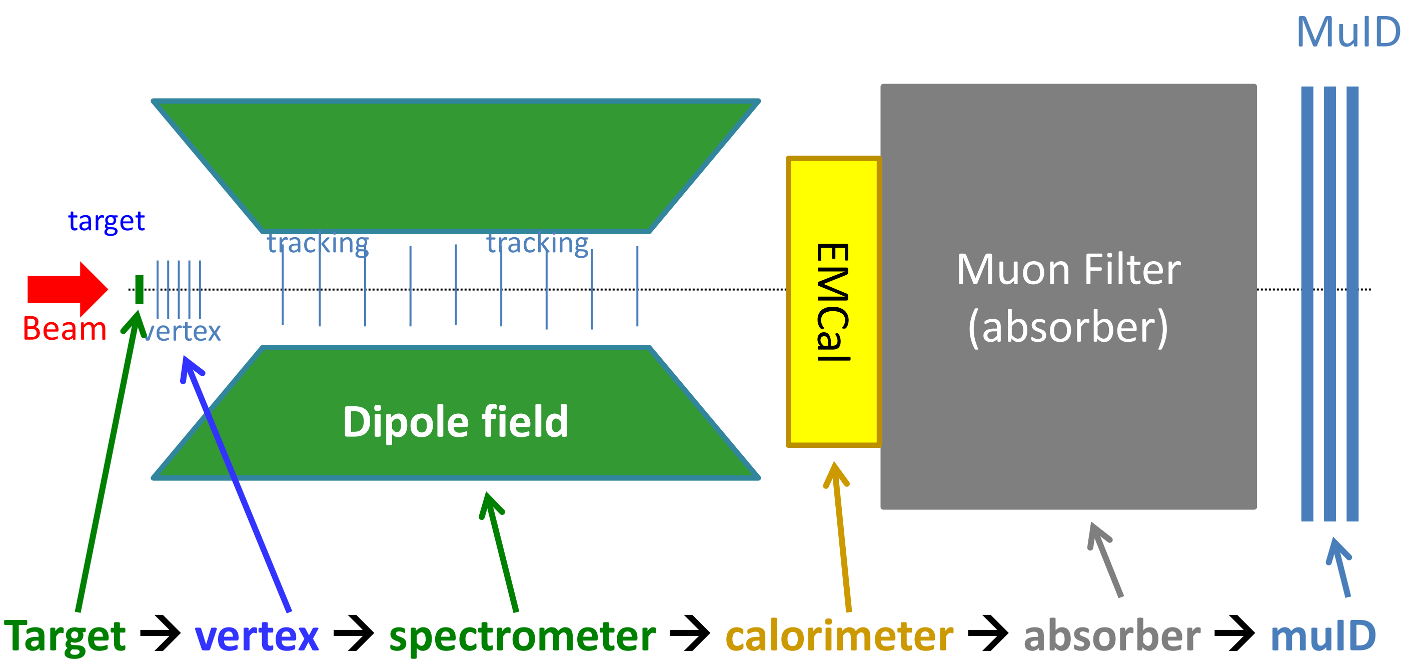
2nd generation: NA60
Measure dimuons and open charm vertex



Target → telescope

CHIC – detector design

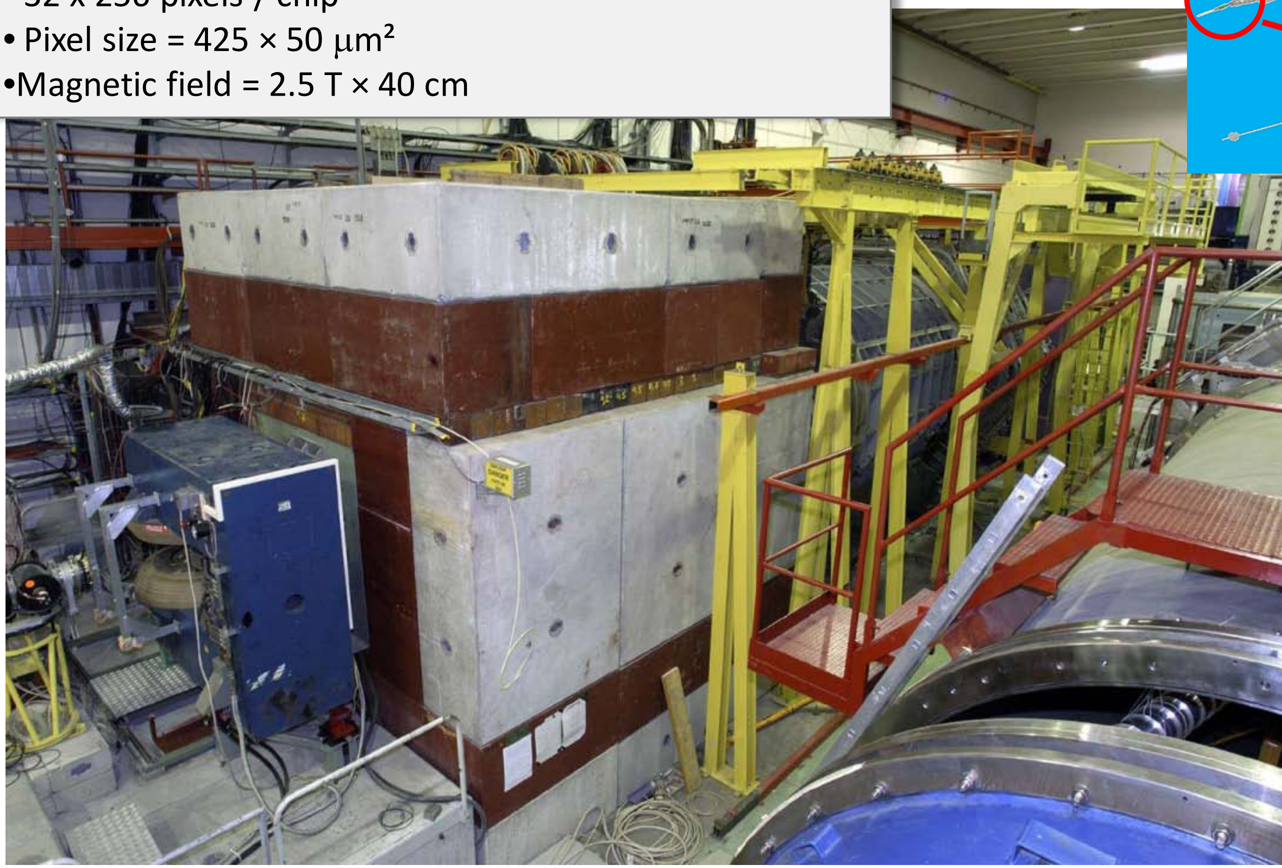
- **3rd generation: CHIC**
  - Measure dimuons and **photons**
    - Must place the **calorimeter in front of the absorber**
    - Must separate photon/electron → **tracking in front of the calorimeter**.

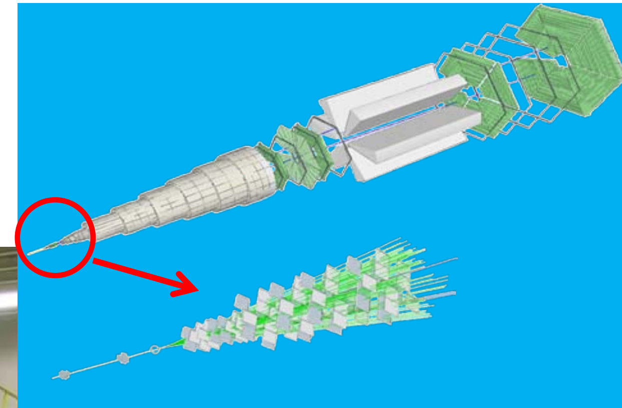


Detector – tracking

- **The NA60 example**

Pixel detector
- 16 planes – 96 chips total
- 32 x 256 pixels / chip
- Pixel size = 425 × 50 μm²
- Magnetic field = 2.5 T × 40 cm





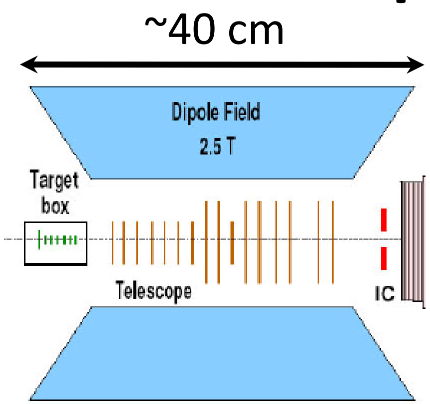
Momentum resolution
@J/Ψ mass
(typical p_{μ} ~ 15 GeV/c)

$$\frac{\Delta P}{P} \sim 6\%$$

(R. S. priv. Comm.)

Detector – tracking

- **The NA60 pixel detector**



$$\frac{\Delta P}{P} = 6\% \Rightarrow \frac{\Delta M}{M} = \frac{\Delta P}{\sqrt{2}P} = 4.2\% \Rightarrow \Delta M_{J/\Psi} \sim 130\ \mathrm{MeV}$$

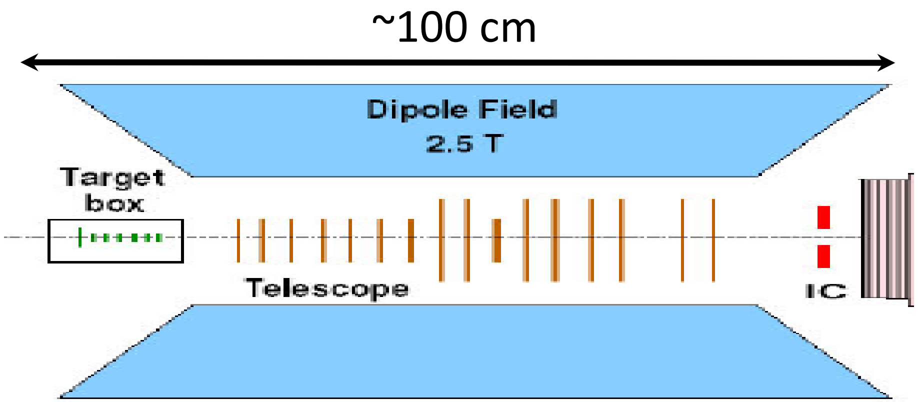
***L* = 0.4 m**

$$\frac{\Delta P}{P} \propto \frac{1}{BL^2} P$$

***L* = 1 m**

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

- **The CHIC pixel detector**



Detector – tracking

- **Size, position, resolution : tentative design – toy**

B (T)	L (cm)	ΔP/P (%)	ΔM (MeV)
2.5	40	~ 6	~120
2.5	60	~ 2.7	~60
2.5	80	~ 1.5	~30
2.5	100	~1	~20

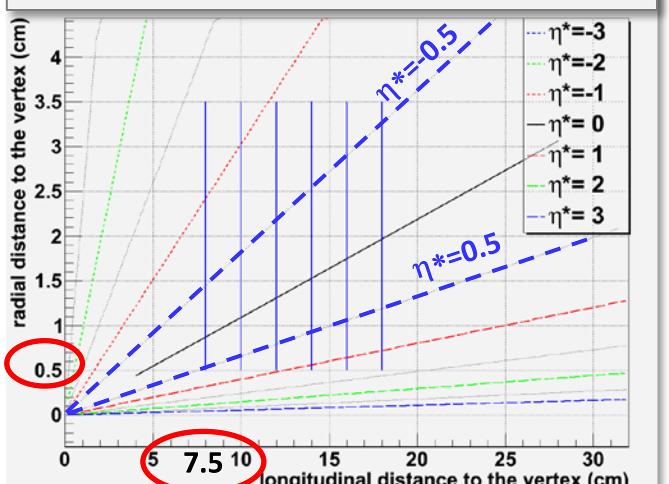
← NA60 (row L = 40 cm)

← CHIC (row L = 100 cm)

6 plane vertex

@ r_{min} = 0.5 cm → $z_{min}(\eta^*=0.5)$~7.5 cm

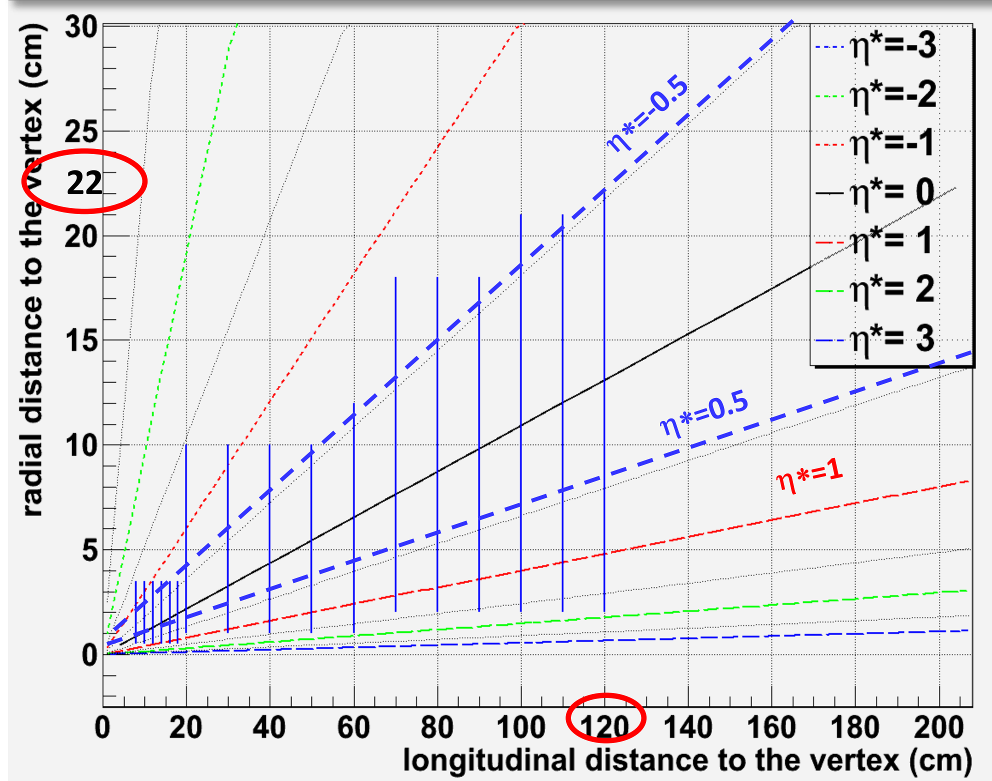
6 planes from z=8 cm to z=18 cm



11 plane spectrometer

@ z_{max} = 120 cm → $r_{max}(\eta^*=-0.5)$~22 cm

11 planes from z=20 cm to z = 120 cm



Track particles within $\eta^* \in [-0.5 ; 1]$

Detector – tracking

- **Size, position, resolution : tentative design - toy**

B (T)	L (cm)	ΔP/P (%)	ΔM (MeV)
2.5	40	~ 6	~120
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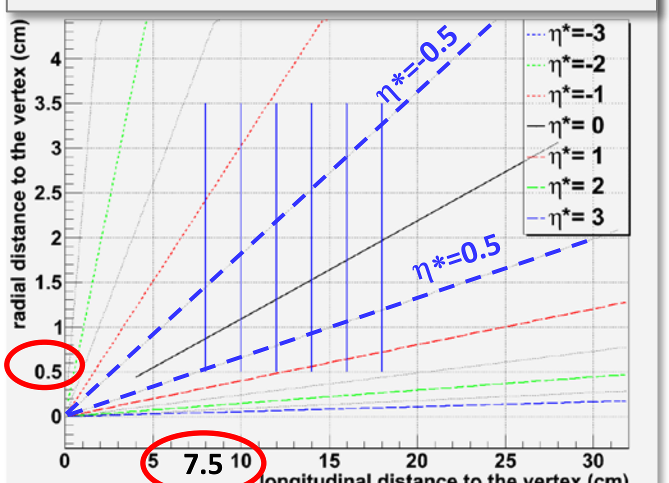
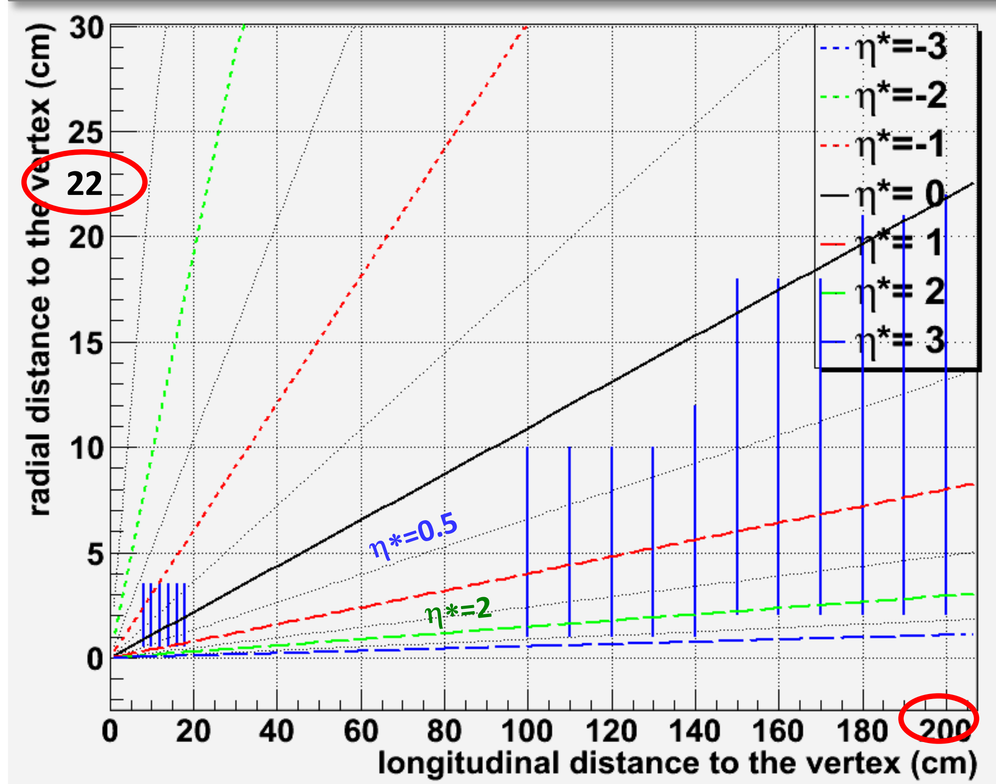


11 plane spectrometer

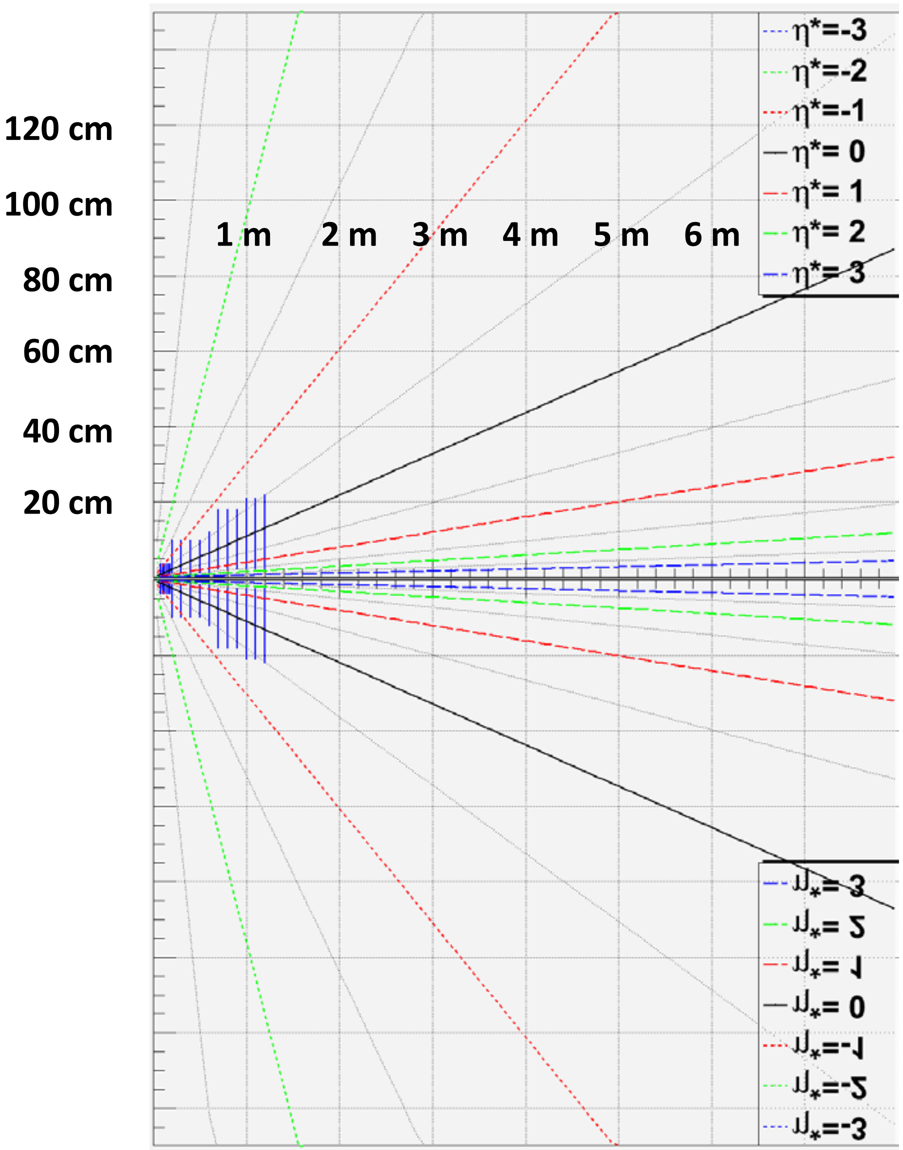
@ z_{max} = 120 cm ➔ $r_{max}(\eta^*=-0.5)$~22 cm

11 planes from z=100 cm to z = 200 cm



Track particles within $\eta^* \in [0.5 ; 2]$

Detector – tentative design



Vertex detector :

R_{min} = 0.5 cm Z_{min} = 7.5 cm

R_{max} = 3.5 cm Z_{max} = 18 cm

Spectrometer :

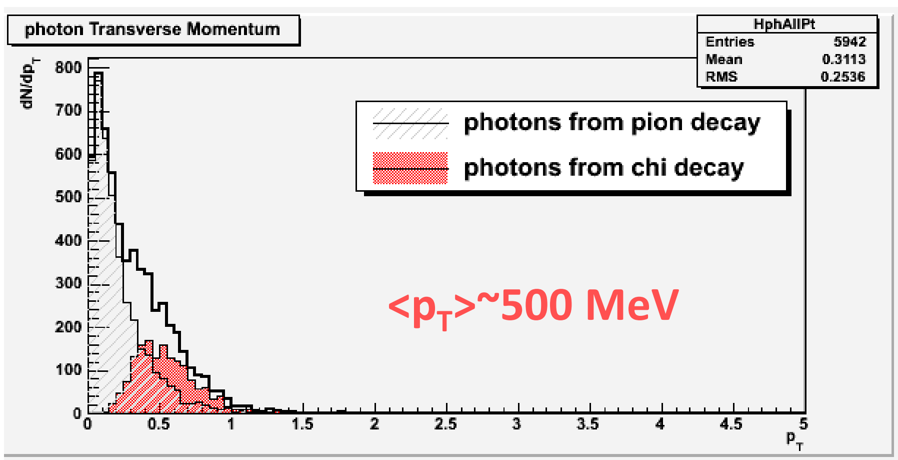
R_{min} = 1 cm Z_{min} = 20 (100) cm

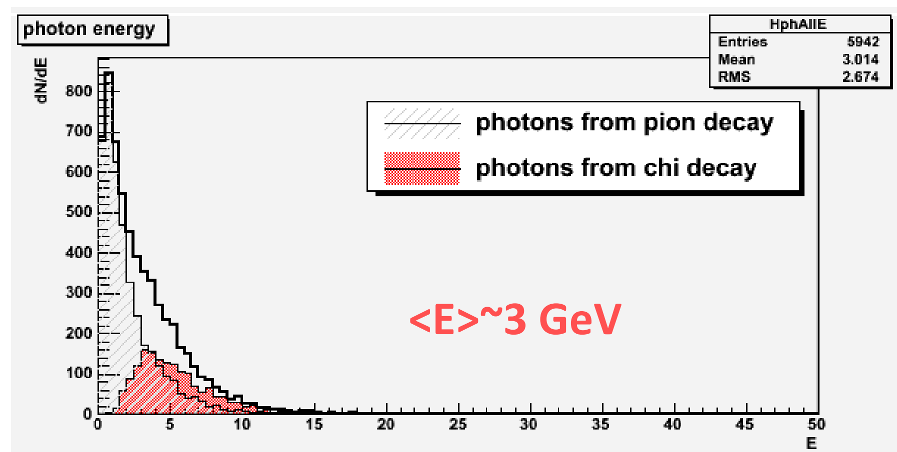
R_{max} = 22 cm Z_{max} = 120 (200) cm

Detector – 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 π^0 /$\eta \rightarrow \gamma\gamma$
  3. High multiplicity of charged particles ($\pi^{+/-}$)

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





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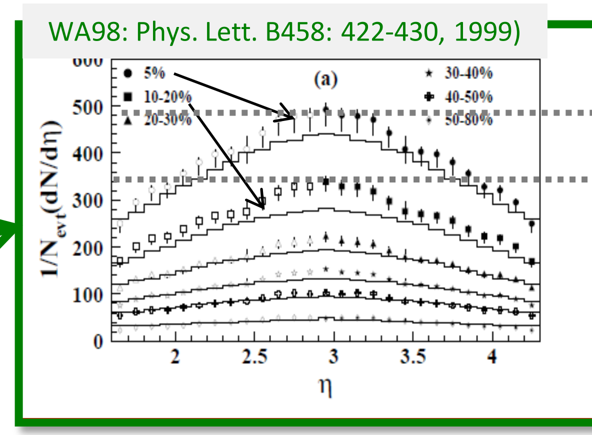
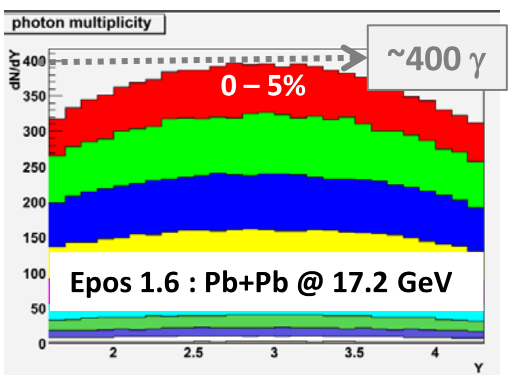
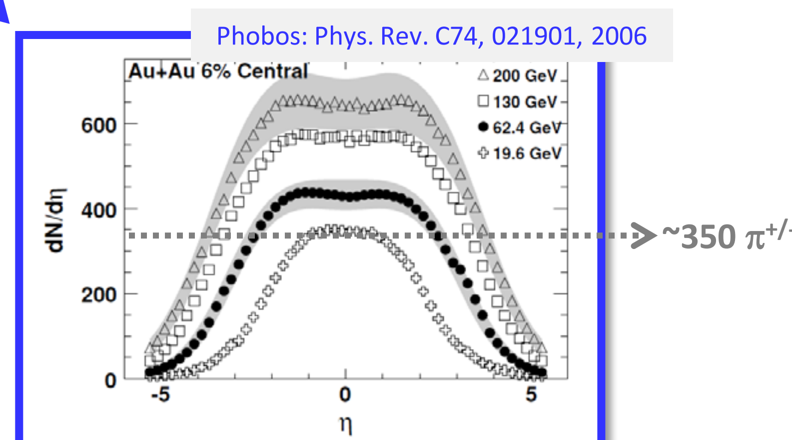
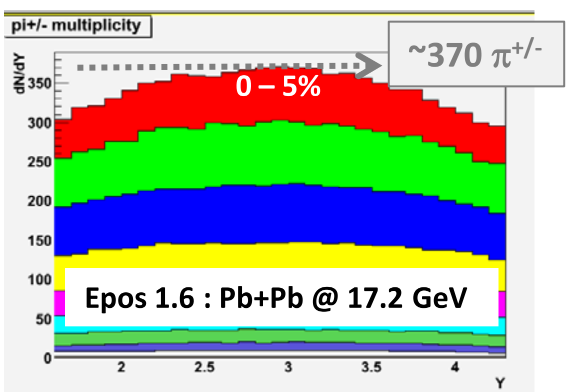




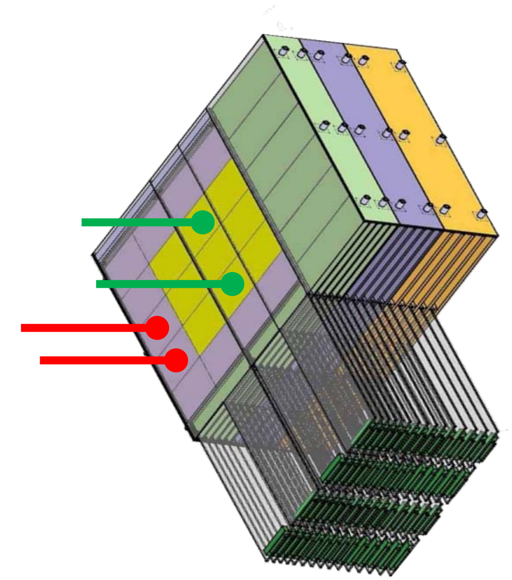




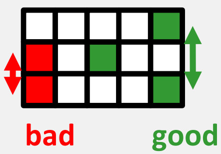
0 – 5% Pb+Pb most central → ~450 γ + 350 $\pi^{+/-}$

Detector – 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



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

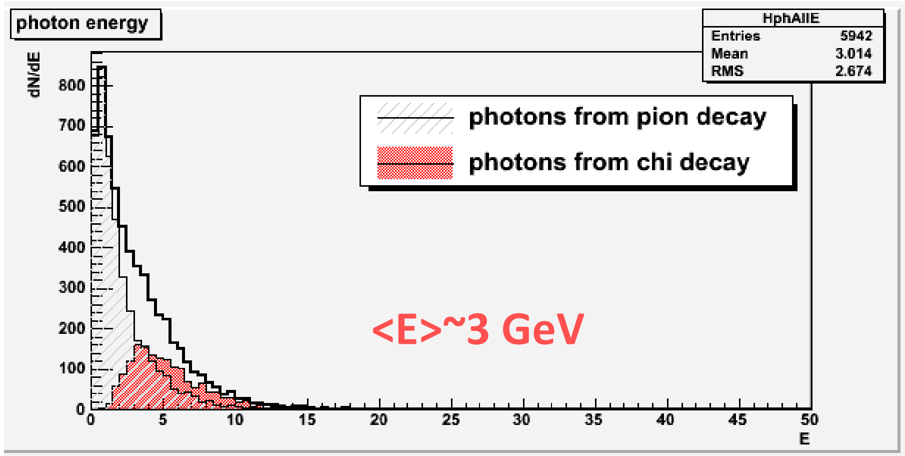
$$\begin{cases} R_M = X_0 \dfrac{21\,\text{MeV}}{610\,\text{MeV}/(Z+1.24)} \\ X_0 = \dfrac{716.4 \times A\ \text{g.cm}^{-2}}{Z(Z+1)\ln\left(287/\sqrt{Z}\right)} \end{cases} \Rightarrow R_M(W) = \frac{17.6\,\text{g.cm}^{-2}}{19.25\,\text{g.cm}^{-3}} \approx 0.9\,\text{cm}$$

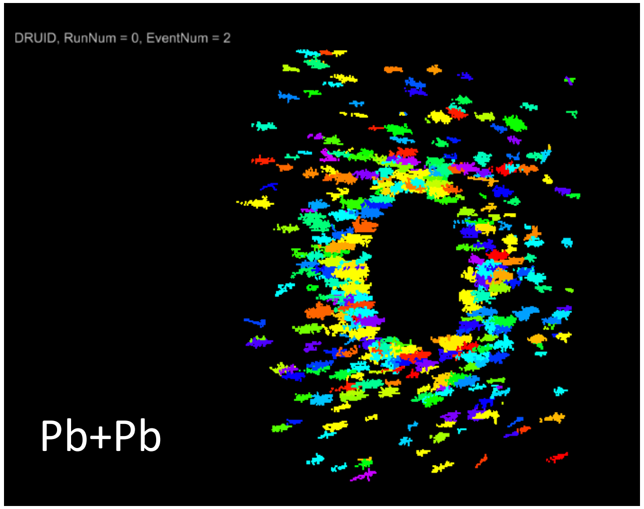
→Distance between two photons must be > 2 cm (2 R_M)

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

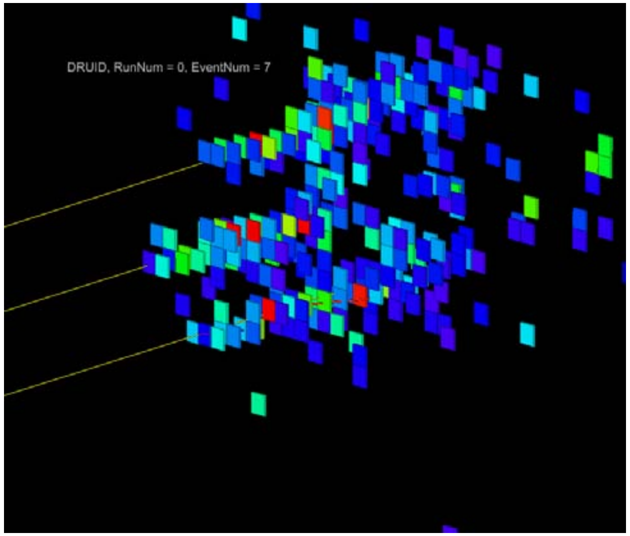
Detector – calorimetry

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





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

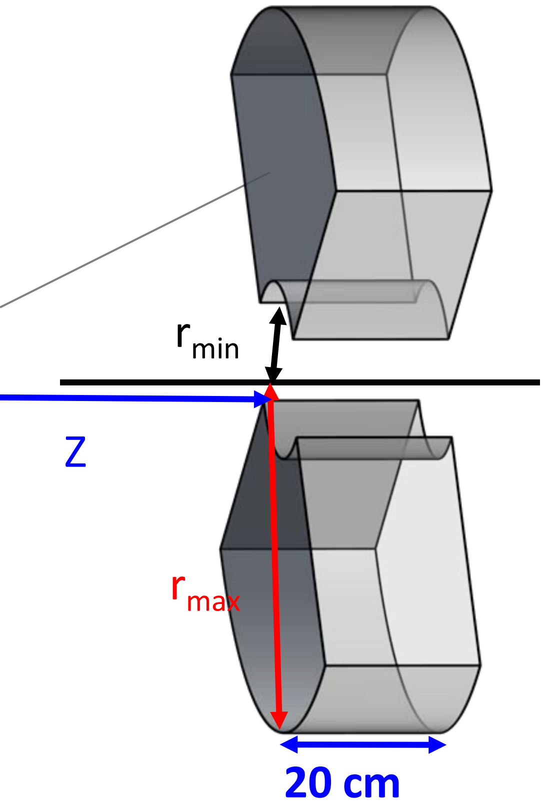


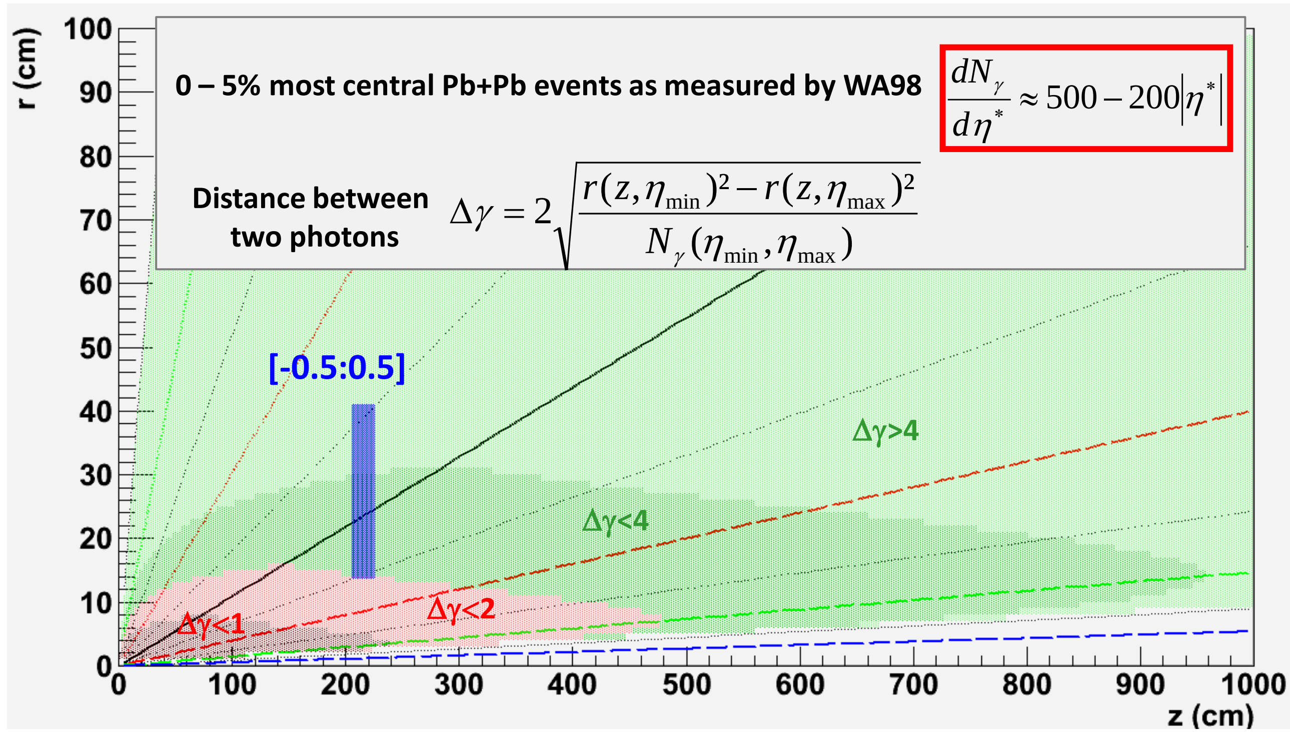
0.5 x 0.5 cm² pads

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

Detector – calorimetry

- **Size and position : tentative design**





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

➔Z = 205 cm [-0.5:0.5]

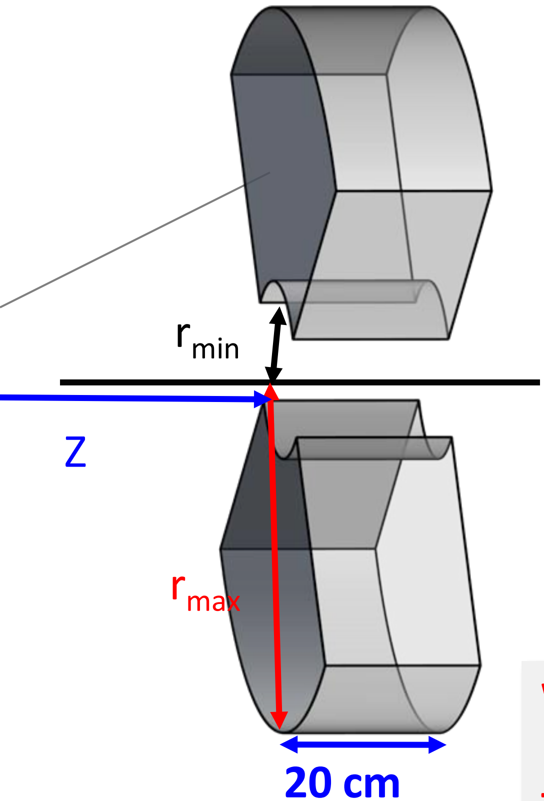
➔R_{min} = 13.6 cm

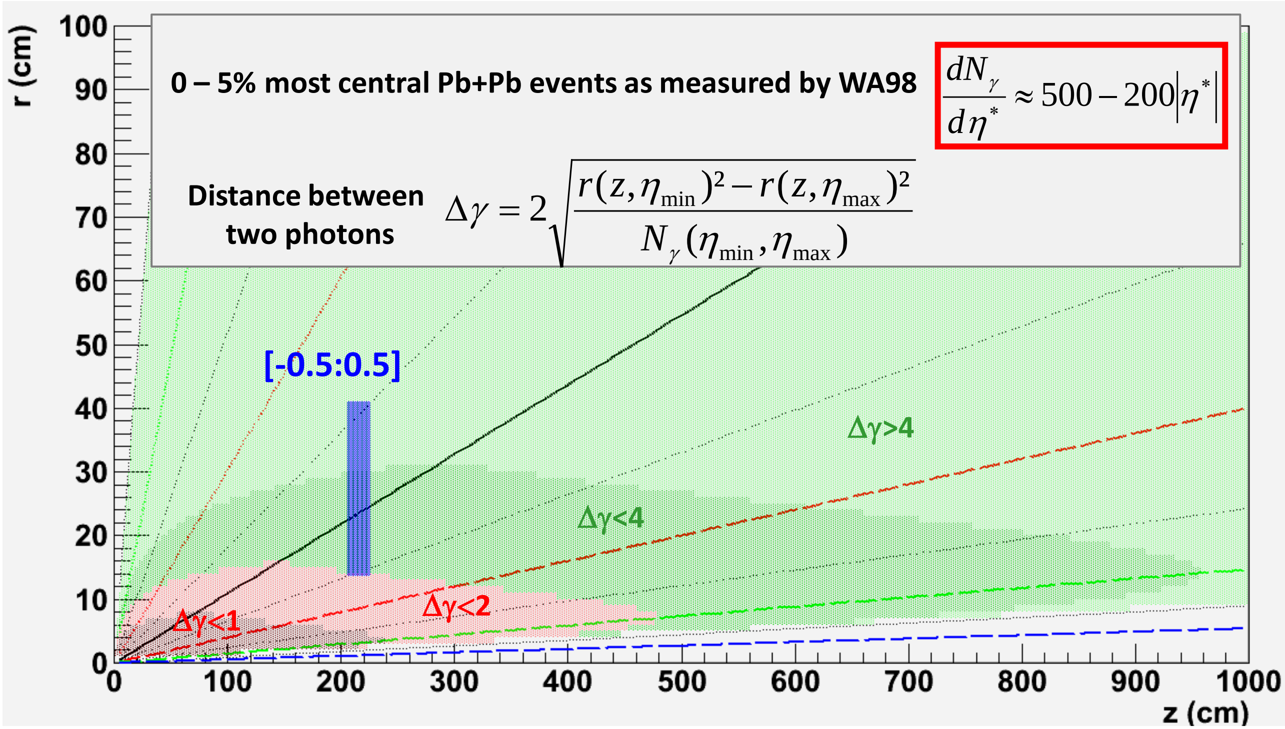
➔R_{max} = 40.9 cm

Using 0.5 x 0.5 cm² pads

Detector – calorimetry

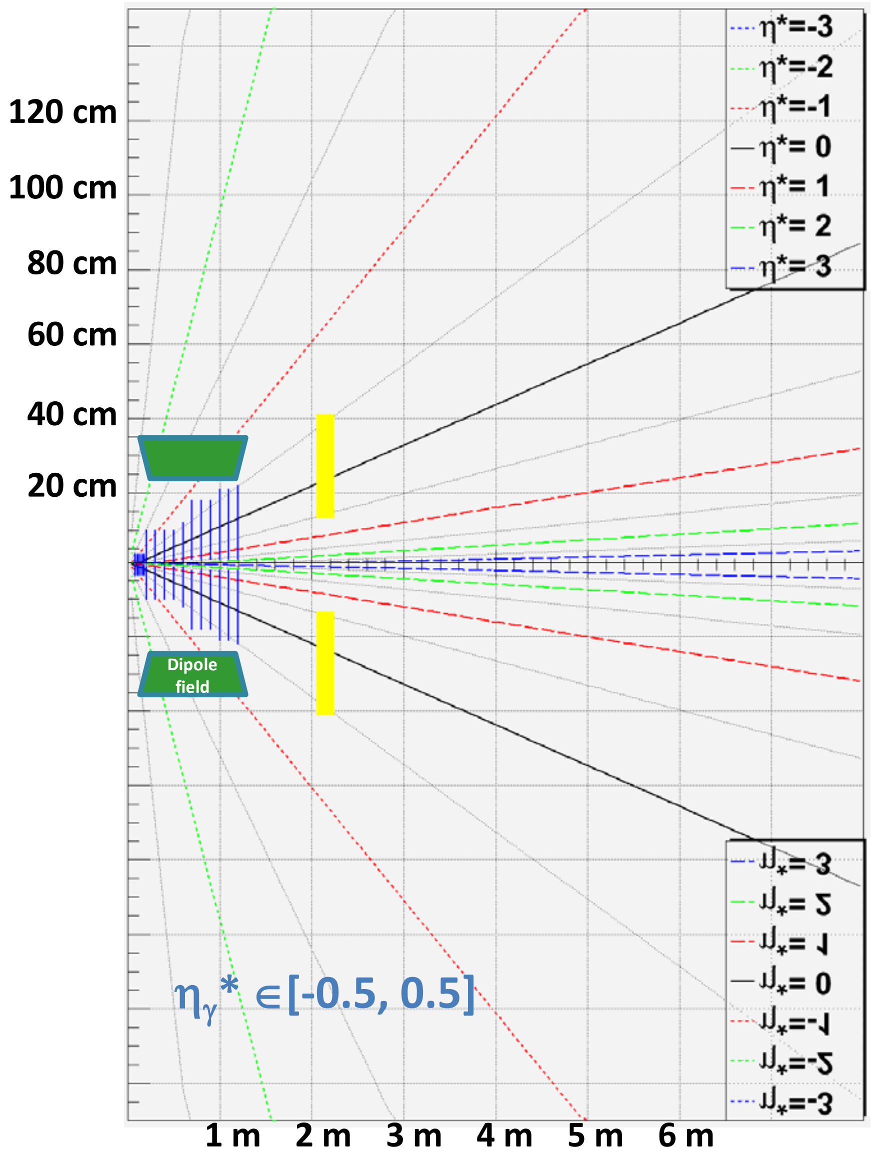
- **Size and position : tentative design**





Warning : not clear that Δγ>2 cm is large enough.
May need to investigate alternative design, for instance:
taking Δγ>4cm with z = 205 cm ➔ $R_{min/max}$=30/55 cm ➔ **η* ∈[-0.8, -0.3]**
taking Δγ>4cm with η* ∈[-0.5, 0.5] ➔ **z ~400 cm**
Must check with full simulation what is optimum Δγ !

Detector – tentative design



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

Calorimeter Δγ>2 cm:

Rmin = 14 cm Zmin = 205 cm
Rmax = 41 cm Zmax = 225 cm

Detector – absorber

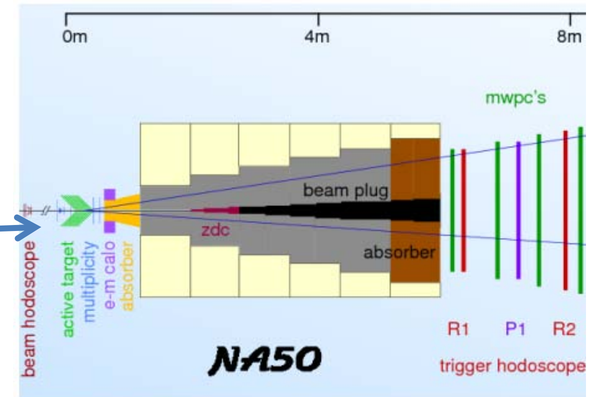
- **Absorber type**

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**

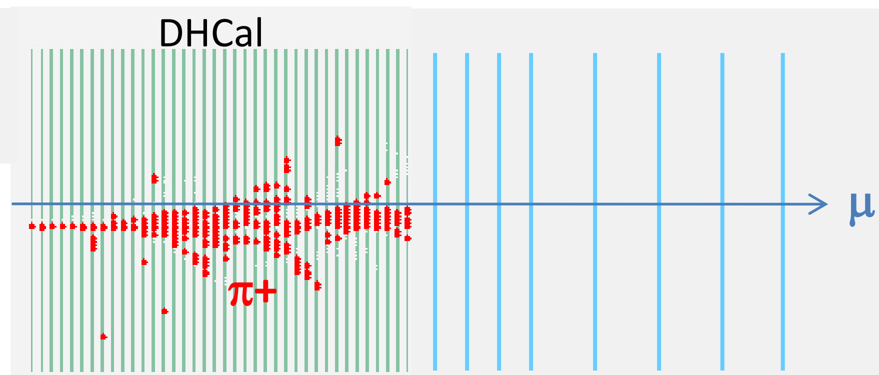


CHIC : measure muon momentum **before** the absorber

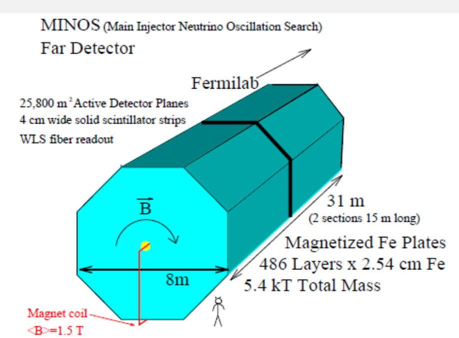
➔ minimization of multiple scattering less crucial

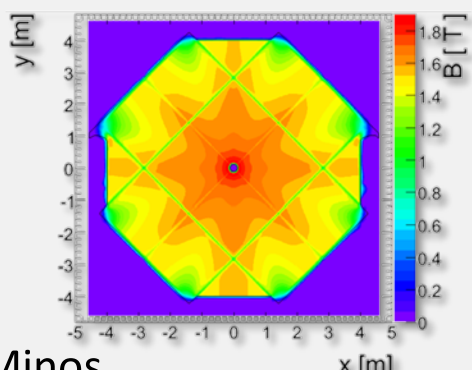
➔ **can use Fe material To absorb $\pi^{+/-}$**

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



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



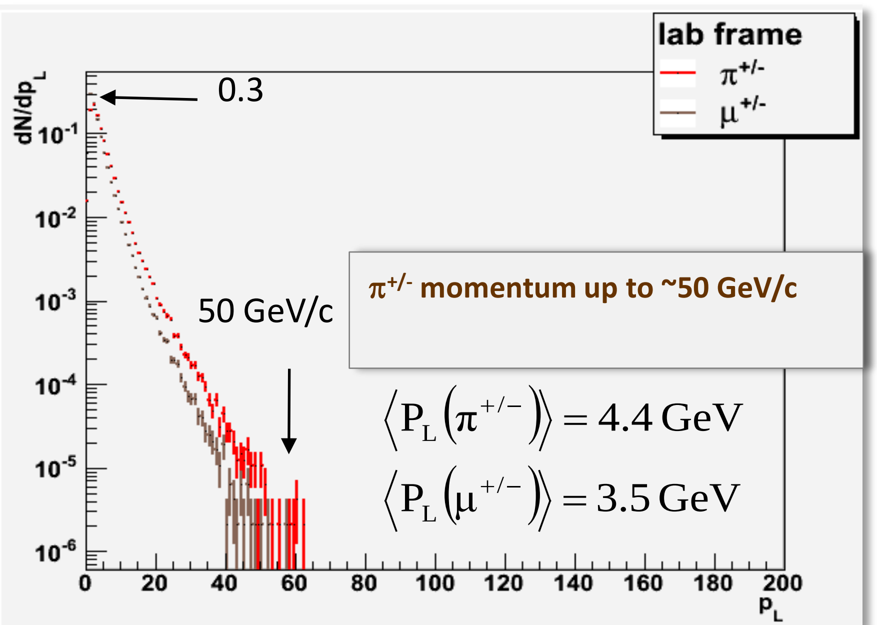


Minos

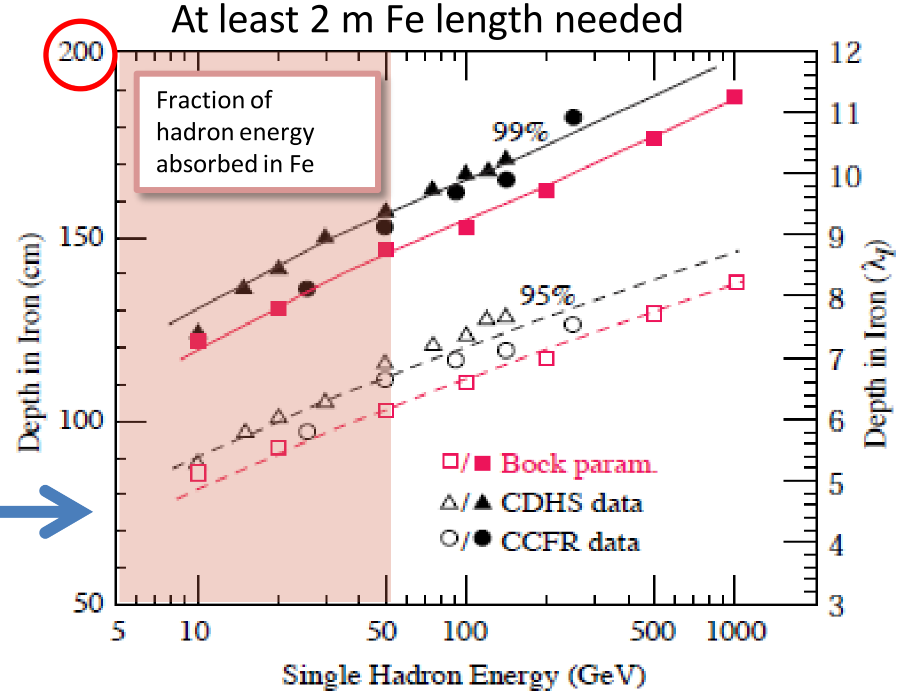
Can match muon track momentum between spectrometer and trigger : **Use magnetized Fe absorber ?**

Detector – absorber

- **Absorber size and energy loss**



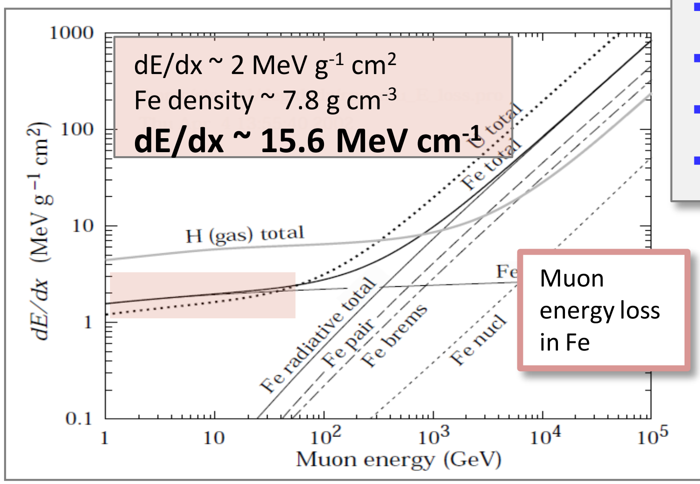
At least 2 m Fe length needed



All $\pi^{+/-}$ stopped with a 2.0 m Fe absorber
but need more Fe to stop muons from pion decay

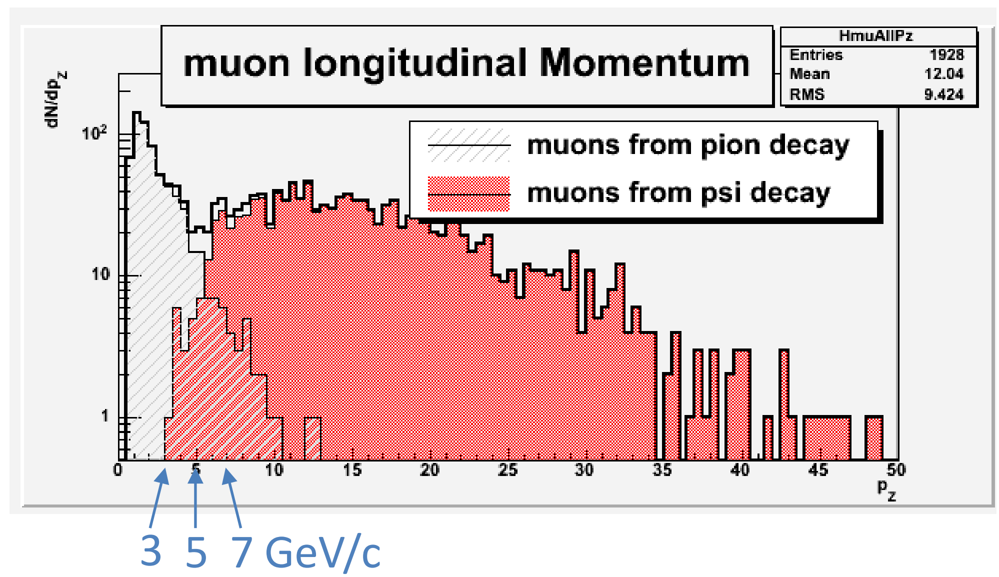
Detector – absorber

- **Absorber size and energy loss**



All $\pi^{+/-}$ stopped with a 2.0 m Fe absorber
but need more Fe to stop muons from pion decay

→ 2.0 m Fe → $\Delta E/\Delta x$ ~ 15.6 x 200 ~ 3.1 GeV → $\mathcal{A}_{J/\Psi}$ ~ 18.4 %
→ **3.2 m Fe** → $\Delta E/\Delta x$ ~ 15.6 x 320 ~ 5 GeV → $\mathcal{A}_{J/\Psi}$ ~ 18.0 %
→ **3.8 m Fe** → $\Delta E/\Delta x$ ~ 15.6 x 380 ~ 6 GeV → $\mathcal{A}_{J/\Psi}$ ~ 17.3 %
→ **4.5 m Fe** → $\Delta E/\Delta x$ ~ 15.6 x 450 ~ 7 GeV → $\mathcal{A}_{J/\Psi}$ ~ 16.1 %

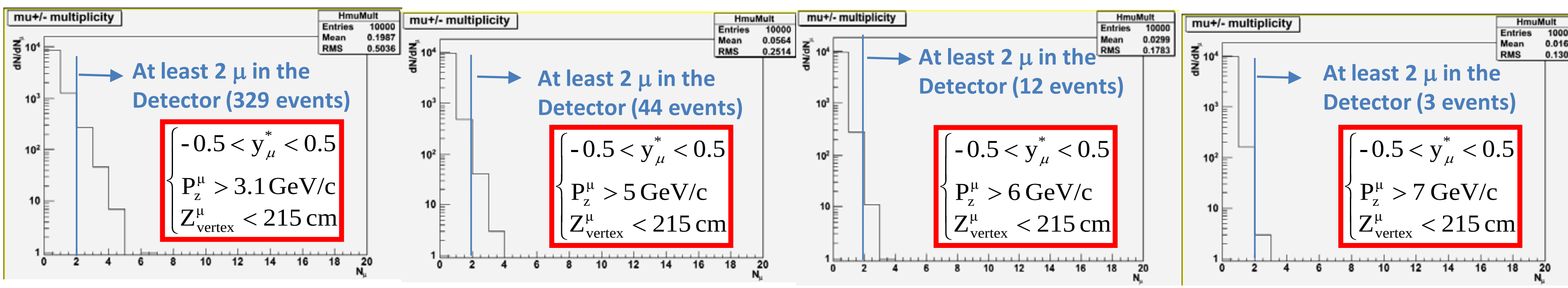


Absorber starts @ 205 cm
$\pi^{+/-}$ stop decaying after 1 λ_I in tungsten (λ_I~10cm)
→ **$\pi^{+/-}$ stop decaying @ 2.15 m**

Detector – trigger rate in Pb+Pb

- **Pb Beam intensity**
  - NA50 → 5.10^7 ions/bunch → 10^7 ions/sec (with a bunch time length ~ 5 sec)
  - **Luminosity : $\mathcal{L}$ =** $N_b x N_T = N_b \times (\rho \times e \times \mathcal{N}_A)/A = 10^7 \times (11.35 \times 0.4 \times 6.02\ 10^{23})/207.19 =$ **$0.12 \mu b^{-1} s^{-1}$**
- **Number of min bias events (for Pb+Pb)**
  - $\sigma_I = 68.8 \times (A^{1/3}_{proj} + B^{1/3}_{targ} - 1.32)^2$ → **$\sigma^{PbPb}_{minbias}$**$= 68.8 \times (208^{1/3} + 207.19^{1/3} - 1.32)^2 =$ **7.62 barn**
  - **Nevents/sec** ~ $0.12\ 10^6 \times 7.62$ **~ 0.9 MHz**

- **Event rejection :** **10 000 Pb+Pb minbias events generated with EPOS 1.6**



3.2m Fe abs.: P_z>5 GeV/c: Trigger accepts 44/10000 events → **N_{events}/sec** ~ 0.9 MHz x 4.4 10^{-3} **~ 4 kHz**
3.8m Fe abs.: P_z>6 GeV/c: Trigger accepts 12/10000 events → **N_{events}/sec** ~ 0.9 MHz x 1.2 10^{-3} **~ 1.1 kHz**
4.5m Fe abs.: P_z>7 GeV/c: Trigger accepts 3/10000 events → **N_{events}/sec** ~ 0.9 MHz x 3 10^{-4} **~ 270 Hz**

CHIC – Detector design

- **Primary goals :**
  - $\chi_c \rightarrow J/\Psi + \gamma \rightarrow \mu^+ \mu^- \gamma$ at $y_{CMS} = 0$
  - $J/\Psi \rightarrow \mu^+ \mu^-$ in large y_{CMS} range
- **Detector features : very compact**

1. Spectrometer

   - Measure tracks before absorber ➔ σ_M~20 MeV/c²

   - Covers y_{CMS} [-0.5, 2] ➔ need high segmentation

   ➔ Silicon technologies

2. Calorimeter

   - Measuring γ in high π^0 multiplicity environment

   ➔ ultra-granular EMCal (Calice)

3. Absorber/trigger

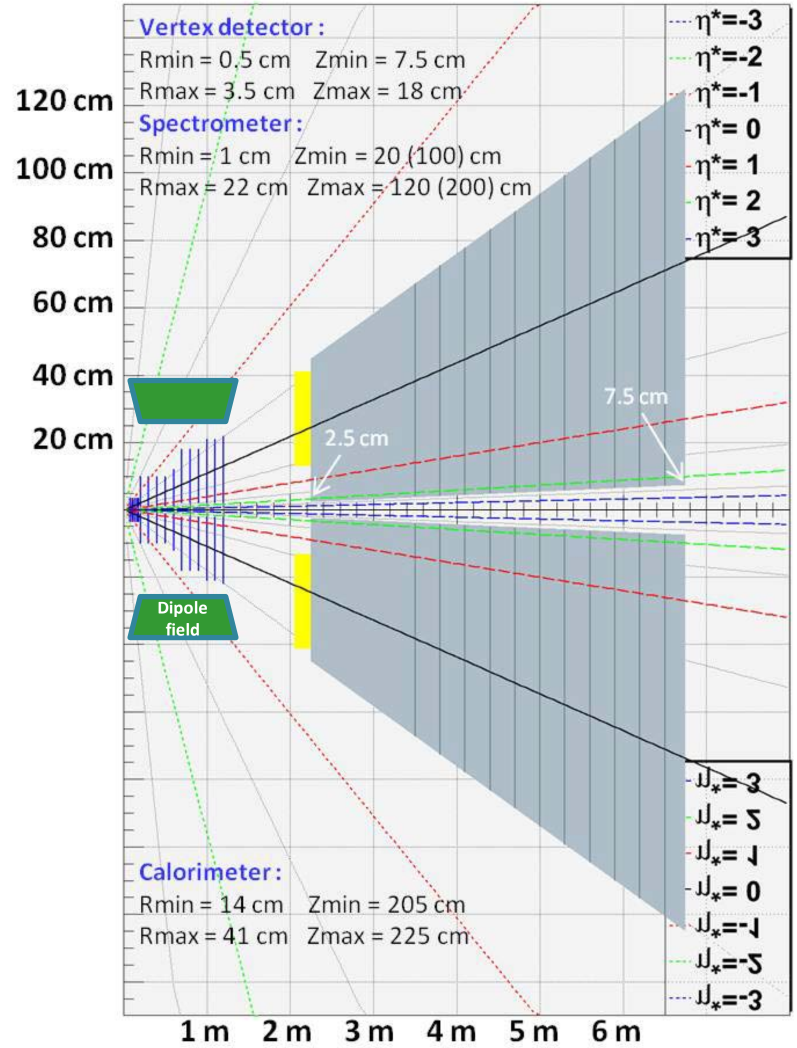
   - Using 4.5 m thick Fe to absorb π/K and low P $\mu^{+/-}$

   - Can use smaller absorber if Fe magnetized

   - Trigger to be defined (expected rate = 0.3 kHz)

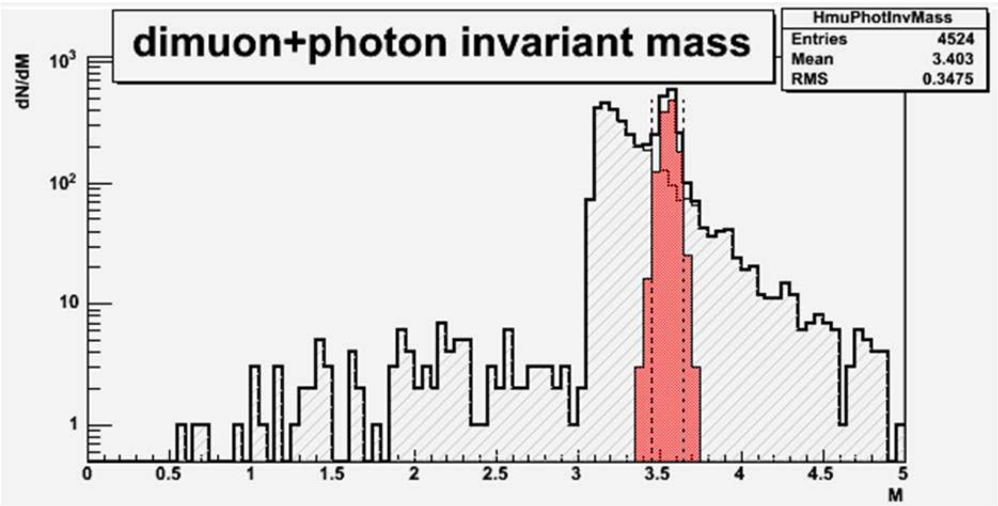
- **Expected performances**

1. tracking : $\frac{\Delta P}{P} \sim 1\%$ within 1m long 2.5T $\vec{B}$
2. Calorimetry : $\frac{\Delta E}{E} \sim \frac{20\%}{\sqrt{E}}$

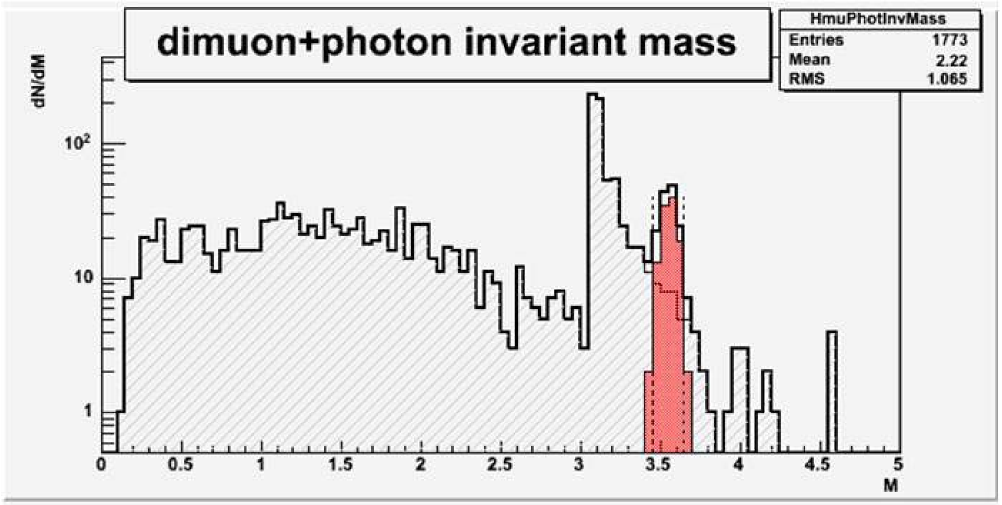


CHIC – Performances

- χ_{c2} **in p+p collisions at $\sqrt{s}$=17.8 GeV**
  - **Sample:**
    - 20 000 events with Pythia 6.421
    - 1 $\chi_{c2} \rightarrow J/\Psi\ \gamma \rightarrow \mu^+ \mu^- \gamma$ per event
    - Smearing $\Delta P_\mu / P_\mu$ = 1%
    - Smearing $\Delta E_\gamma / E_\gamma = 20\%/\sqrt{E_\gamma}$
  - **Selections :**
    - Keep muons w/ $-0.5 < y_{cms} < 0.5$
    - Keep muons w/ $P_z > 7$ GeV
    - Keep muons w/ $z_{vertex} < 215$ cm
    - Keep photons w/ $-0.5 < y_{cms} < 0.5$
    - Reject photons w/ $M_{\gamma\gamma} \in [100, 160]$ MeV/c²
  - **Results** : signal/bkg = 2.8



- χ_{c2} **in Pb+Pb at $\sqrt{s}$=17.8 GeV**
  - **Sample:**
    - 10 000 events minbias with Epos 1.6
    - 1 pythia χ_{c2} embedded in each event
    - Same selections as in p+p
    - Reject γ if not in the same emisphere as J/Ψ
  - **Results** : signal/bkg = 3.6

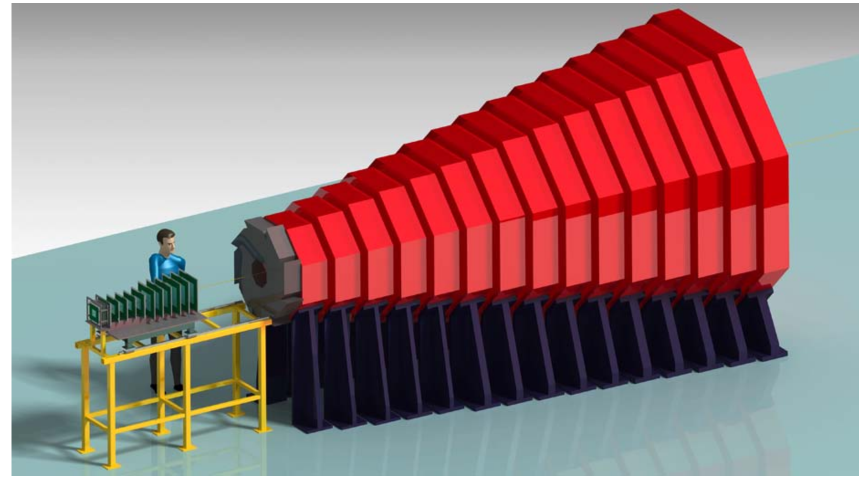


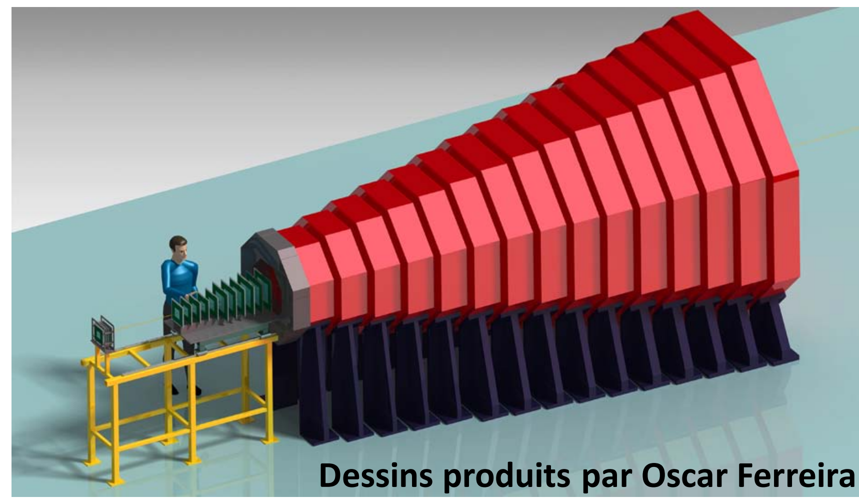
Conclusion

- Déjà beaucoup de données sur le J/Ψ à différentes énergies, d'autres à venir
- Toujours difficile à comprendre:
  - A-t-on vu la suppression séquentielle ?
  - A-t-on vu la régénération ?
- La mesure du χ_c est une étape essentielle (et nécessaire)
- Le SPS est le meilleur endroit pour commencer
- C'est aujourd'hui faisable

- **Programme pour 2012**
  - Promotion du projet : séminaires, conférences
  - **Recherche de partenaires**
  - Première version d'un framework de simulation
  - Évaluation des technologies (tracking, muons)
  - Échelle de temps < 10 ans (~3 construction)
  - Échelle de prix ~3 – 4 M€

- **Demandes :**
  - Quelques aides ponctuelles
  - **Des encouragements**





Dessins produits par Oscar Ferreira

Conclusion

Expression of Interest

CHIC: Charm in Heavy Ion Collisions

Study of charm production with proton and heavy ion beams at the CERN SPS

E. G. Ferreiro, Universidad de Santiago de Compostela, Spain
F. Fleuret, LLR-École polytechnique, CNRS/IN2P3, Palaiseau, France

Abstract

We propose a third generation experiment devoted to the measurement of open and hidden charm production in heavy ion collisions. The specific purpose of this experiment is to measure $\chi_c \rightarrow J/\psi + \gamma$ in the very busy environment produced in Pb+Pb collisions. This will lead to the first observation of charmonium sequential suppression in a Quark Gluon Plasma.