AFTER/CHIC experimental connections

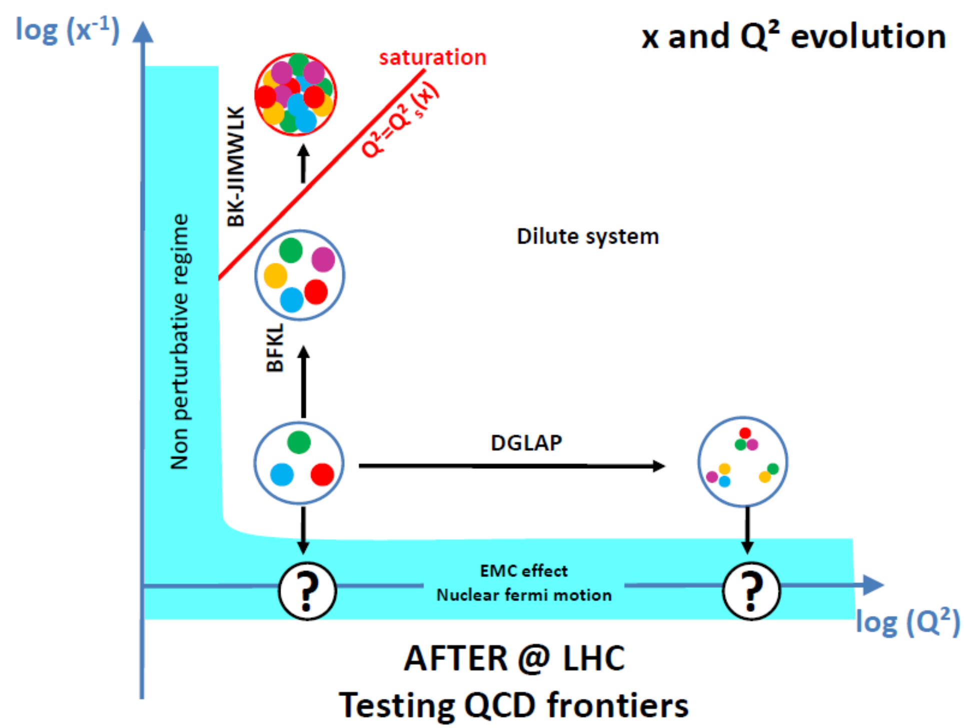
Two different physics cases
with a common apparatus concept

1. AFTER@LHC : experimental constraints
2. CHIC@SPS : experimental design

AFTER @ LHC – Physics

- **Idea : use LHC beam on fixed target**
  - *7 TeV proton beam (√s ~115 GeV)*
    - *p+p, p+A*
  - *2.75 TeV Pb beam (√s ~72 GeV)*
    - *Pb+A, Pb+p*
- ***High boost and luminosity giving access to***
  - *QCD at large x*
  - *nPDF and nuclear shadowing*
  - *QGP*
  - *Spin physics*
  - *Other ?*

See Stan's talk

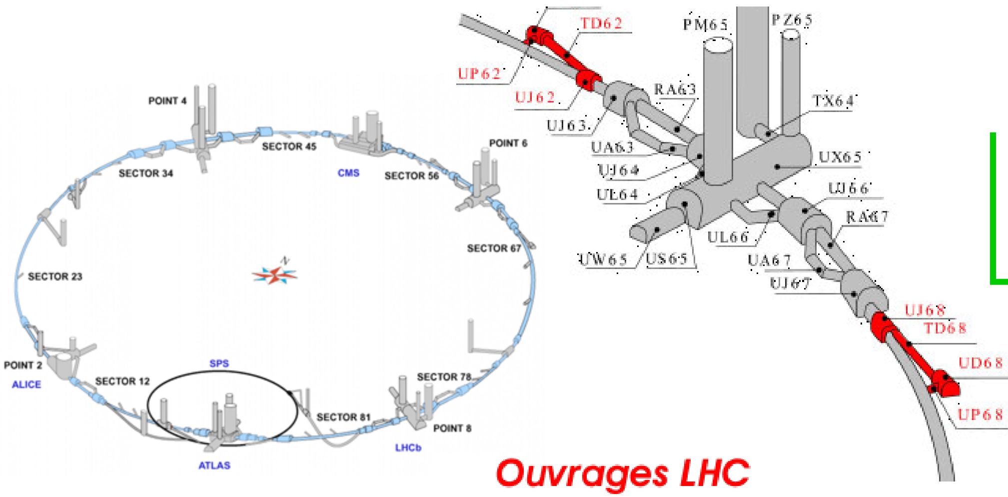


AFTER @ LHC
Testing QCD frontiers

AFTER @ LHC – Beam extraction

- **Beam extraction @ LHC**

We propose to insert a 17 cm long, uniformly bent Si crystal at the MKD kicker section, the crystal centered at a distance of 192 710 mm from IP6.



… The idea is to put a bent, single crystal of either Si or Ge (W would perform slightly better but needs substantial improvements in crystal quality) at a distance of $\simeq 7\sigma$ to the beam where it can intercept and deflect part of the beam halo by an angle similar to the one the foreseen dump kicking system will apply to the circulating beam.

Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
ELSEVIER
Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

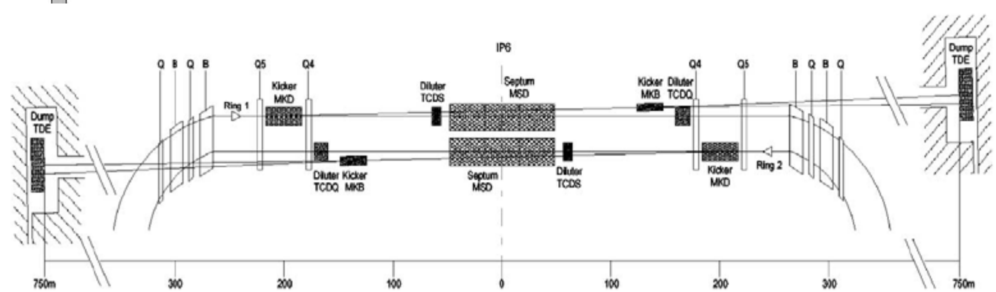
Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj *

The beam loss from the LHC is predicted to be of the order 10^9 p^+/s [24].

… a realistic figure for the extraction efficiency is 50% yielding an extracted beam of about 5×10^8 p^+/s.

N_{beam} ~ 5 x 10^8 p^+/s



AFTER @ LHC – p+A Luminosity

- **Intensity: expect 5.10^8 protons.s^{-1}**
  - **Beam:** 2808 bunches of 1.15×10^{11} protons = **3.2×10^{14} protons**
  - **Bunch:** Each bunch passes IP at the rate: 3.10^5km.s^{-1}/27 km ~ **11 kHz**
  - **Instantaneous extraction:** IP sees 2808 x 11000~3.10^7 bunches passing every second
    ➔ extract $5.10^8/3.10^7$ ~ **extract 16 protons in each bunch at each pass**
  - **Integrated extraction:** Over a 10h run: extract 5.10^8p x 3600s.h^{-1} x 10h=1.8 10^{13}p.run^{-1}
    ➔ extract 1.8 x 10^{13}/(3.2 x 10^{14})~**5.6% of the protons stored in the beam**

- **Instantaneous Luminosity**
  $\mathcal{L} = N_{beam} \times N_{Target} = N_{beam} \times (\rho \times e \times \mathcal{N}_A)/A$
  - N_{beam}=5 x 10^8 p^+/s
  - **e** (target thickness) = 1 cm

- **Integrated luminosity**
  - 9 months running/year
  - ➔ 1year ~ 10^7 s
  - ➔ $\int_{year}\mathcal{L} = \mathcal{L}_{inst}\times10^7$

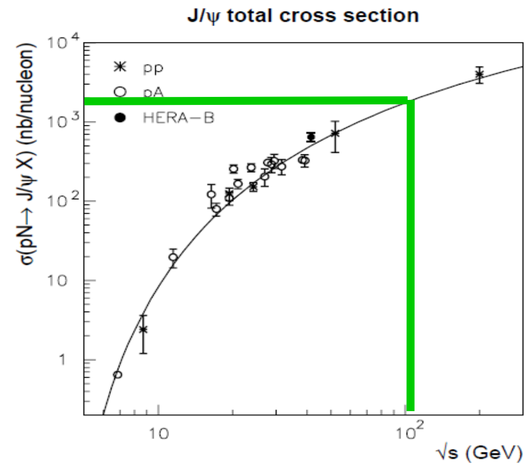
1 cm thick target

Targ	ρ (g.cm^{-3})	A	$\mathcal{L}_{inst}$ ($\mu b^{-1}.s^{-1}$)	$\int_{year}\mathcal{L}$ ($pb^{-1}.y^{-1}$)
Liq H	0.068	1	**20**	**200**
Liq D	0.16	2	**24**	**240**
Be	1.85	9	**62**	**620**
Cu	8.96	64	**42**	**420**
W	19.1	185	**31**	**310**
Pb	11.35	207	**16**	**160**

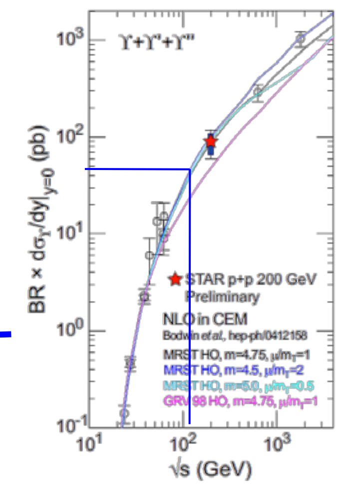
AFTER @ LHC – p+A Luminosity

- **Typical numbers**
  - **J/Ψ @ √s=115 GeV**
    - **σ_{Ψ} ~ 1.5 10^3 nb**

    ➔ **$Br_{\Psi \to e+e-} d\sigma_{\Psi}/dy(y=0)$ ~ 30 nb**



  - **ϒ @ √s=115 GeV**
    - **$Br_{\Upsilon \to e+e-} d\sigma_{\Upsilon} /dy(y=0)$@ 115 GeV ~ 50 pb**



With 1 cm thick target

Target	ρ ($g.cm^{-3}$)	A	$\mathcal{L}$ ($\mu b^{-1}.s^{-1}$)	$\mathcal{L}$ ($pb^{-1}.y^{-1}$)	$N_{J/\Psi}\|_{y=0}$ (y^{-1}) $N_{J/\Psi} = A\mathcal{L}\sigma_{\Psi}$	$N_{\Upsilon}\|_{y=0}$ (y^{-1}) $N_{\Upsilon} = A\mathcal{L}\sigma_{\Upsilon}$
Liq H	0.068	1	**20**	**200**	**6 10^6**	**1. 10^5**
Liq D	0.16	2	**24**	**240**	**1.4 10^7**	**2.4 10^5**
Be	1.85	9	**62**	**620**	**1.6 10^8**	**2.8 10^5**
Cu	8.96	64	**42**	**420**	**8.1 10^8**	**1.3 10^6**
W	19.1	185	**31**	**310**	**1.7 10^9**	**2.9 10^6**
Pb	11.35	207	**16**	**160**	**1. 10^9**	**1.7 10^6**

AFTER @ LHC – Pb+Pb Luminosity

- **Intensity: expect 7.10^5 Pb.s^{-1}**

- **Integrated luminosity**
  - 1 month running/year
  - ➔ 1year ~ 10^6 s
  - ➔ $\int_{year}\mathcal{L} = \mathcal{L}_{inst} x10^6$

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
Liq. H_2	0.07	1	28
Liq. D_2	0.16	2	34
Be	1.85	9	84
Cu	8.96	64	56
W	19.1	185	42
Pb	11.35	207	22

- **Typical numbers : PHENIX @ RHIC recorded in 2010**
  - Au+Au @ 200 GeV: 1.3 nb^{-1}
  - Au+Au @ 62 GeV: 0.11 nb^{-1}

AFTER @ LHC - Pseudorapidity

$\eta^* = \eta - y_{CMS}$

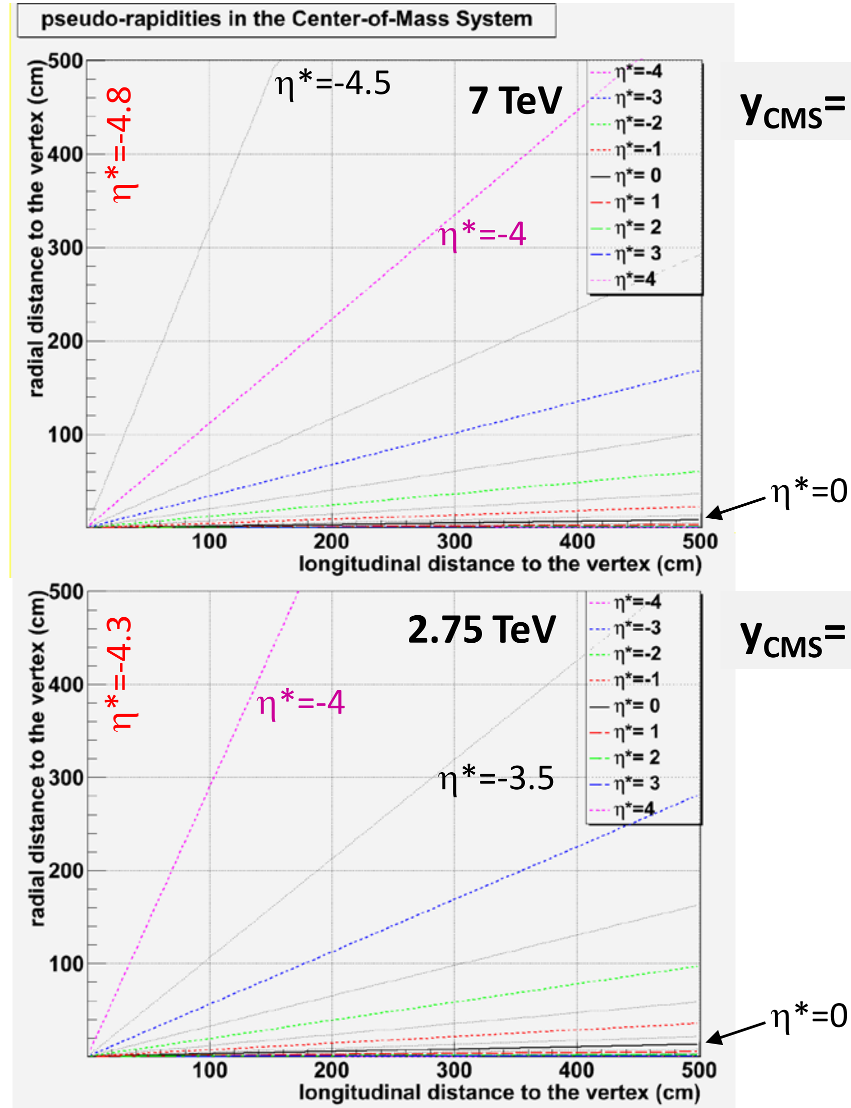
forward region: $\eta^*>0$

backward region: $\eta^*<0$

- ***Very high boost:***
  - *With 7 TeV beam : γ = 61.1*
  - *With 2.75 TeV beam: γ = 38.3*

- ***Very well placed to access backward physics***

- ***Note : taking $x_2 = M/\sqrt{s}\, e^{-y}$***
  - *$x_2(J/\Psi) = 1 \rightarrow y_{J/\Psi} \sim -3.6$*
  - *$X_2(\Upsilon) = 1 \rightarrow y_{\Upsilon} \sim -2.4$*



y_{CMS}= 4.8

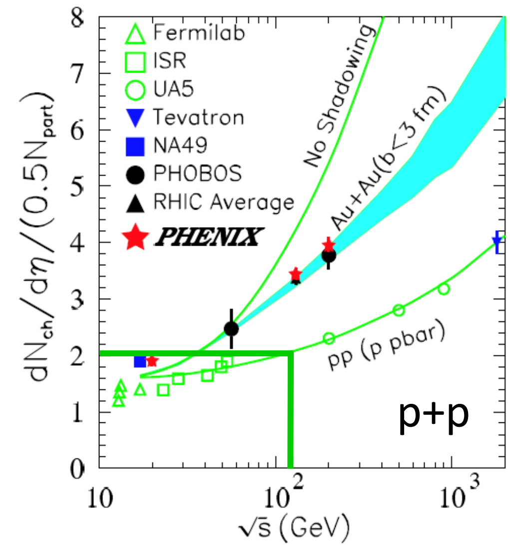
y_{CMS}= 4.3

AFTER @ LHC – Multiplicity

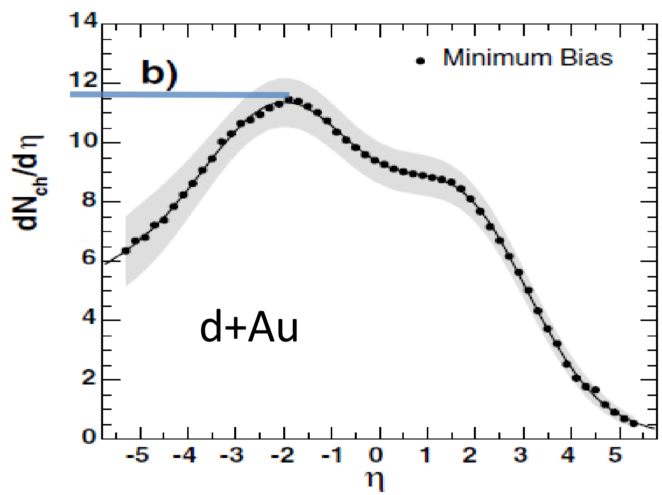
- **Number of charged particles/rapidity unit**

  (1.5 x ~ charged+neutral)

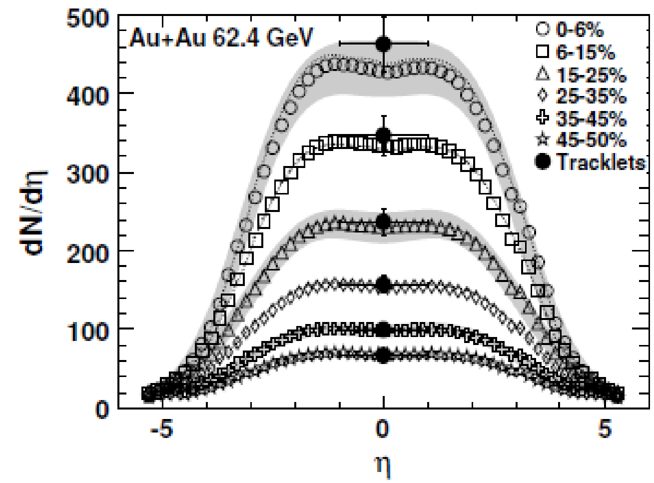
  - **p+p @ 115 GeV ~ 2**
  - **d+Au @ 200 GeV: max~11**
  - **Au+Au @ 62.4 GeV: max~450**



PRL **93, 082301 (2004)**

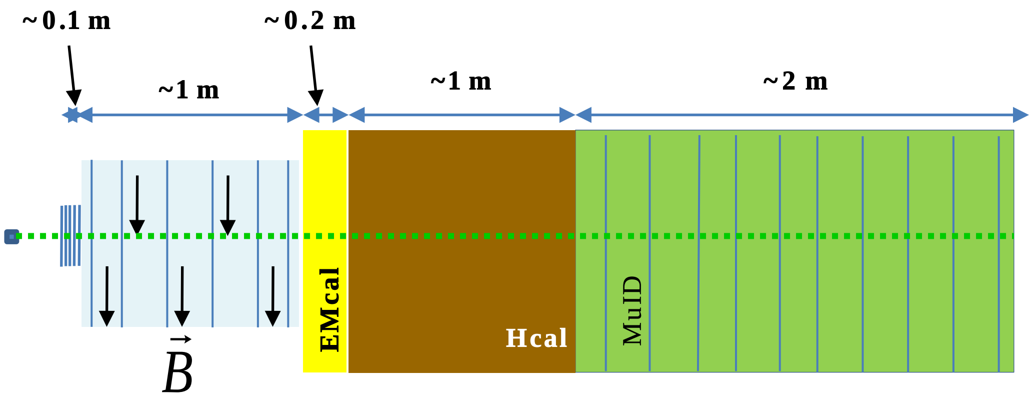


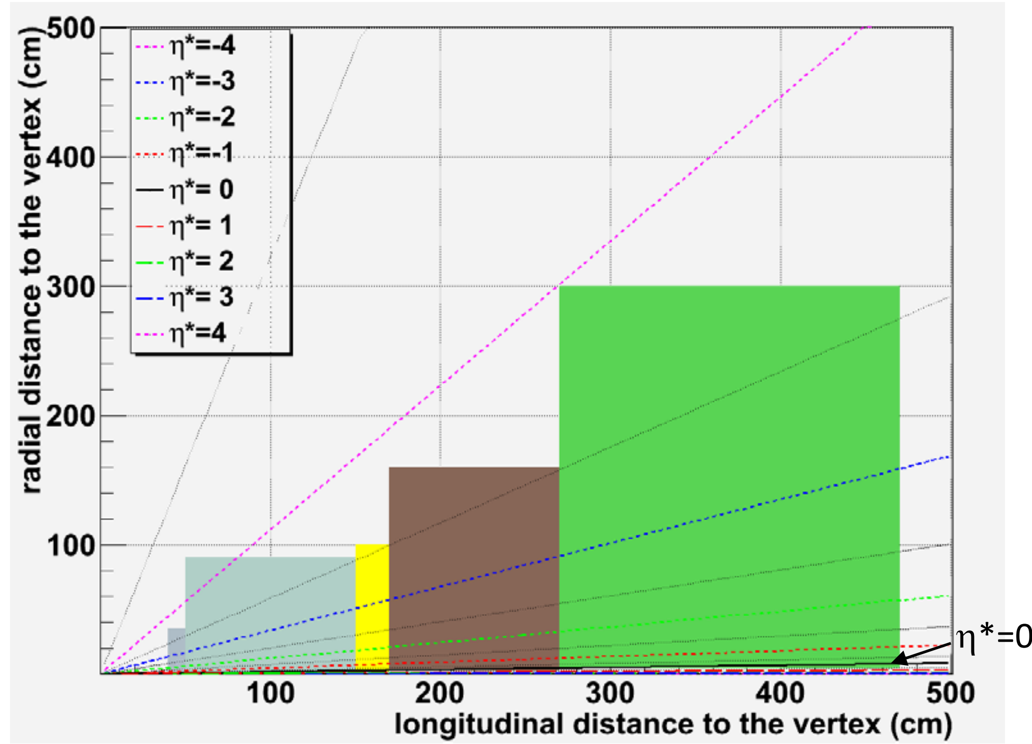
PRC **74, 021901(R) (2006)**



AFTER @ LHC – Detector

- **Typical detector: $-3.5 < y_{cms} < 0$**
  - Multipurpose detector:
    - Vertex
    - Tracking
    - Calorimetry
    - Muons
  - Compact detector
    - Because of the high boost, the detector must be as compact as possible
    - Need ultra-granular technologies

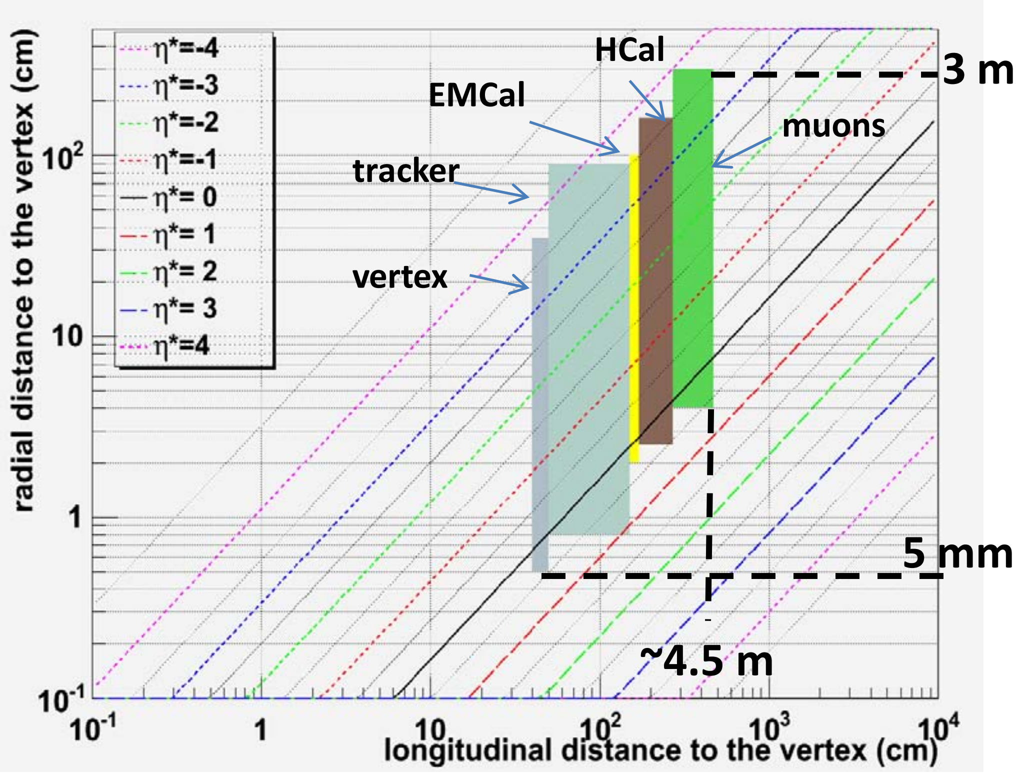




AFTER @ LHC – Detector

- **Dimension**

Detector	Z_{min}/Z_{max}	R_{min}/R_{max}
Vertex	40/50 cm	0.5/35 cm
Tracker	50/150 cm	0.8/90 cm
EMCal	150/170 cm	2/100 cm
Hcal	170/270 cm	2.5/160 cm
muons	270/470 cm	4/300 cm



AFTER @ LHC – Conclusion

- **Wide physics case**
  - QCD at large x
  - nPDF and shadowing
  - QGP
  - Spin
  - Other ?

- **Up to 7 TeV beam**
  - very high boost
  - need ultra-granular (new) technologies

- **Connection with the CHIC experiment @ SPS**
  - Physics : QGP, nPDF and shadowing
  - The CHIC @SPS experiment also needs ultra-granular technologies
  - Take advantage of the CHIC expertise to design AFTER

CHIC @ SPS – Physics case

Test charmonium sequential screening in a QGP

1. **Measure χ_c in A+A @ 17 GeV**

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

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

   Goal: measure $\chi_c \rightarrow J/\Psi\, \gamma \rightarrow \mu^+\mu^-\, \gamma$ within $y_{cms} \in [-0.5, 0.5]$

   Challenge: measure χ_c's γ in a high π^0 multiplicity environment

2. **Measure charmonia production in p+A**

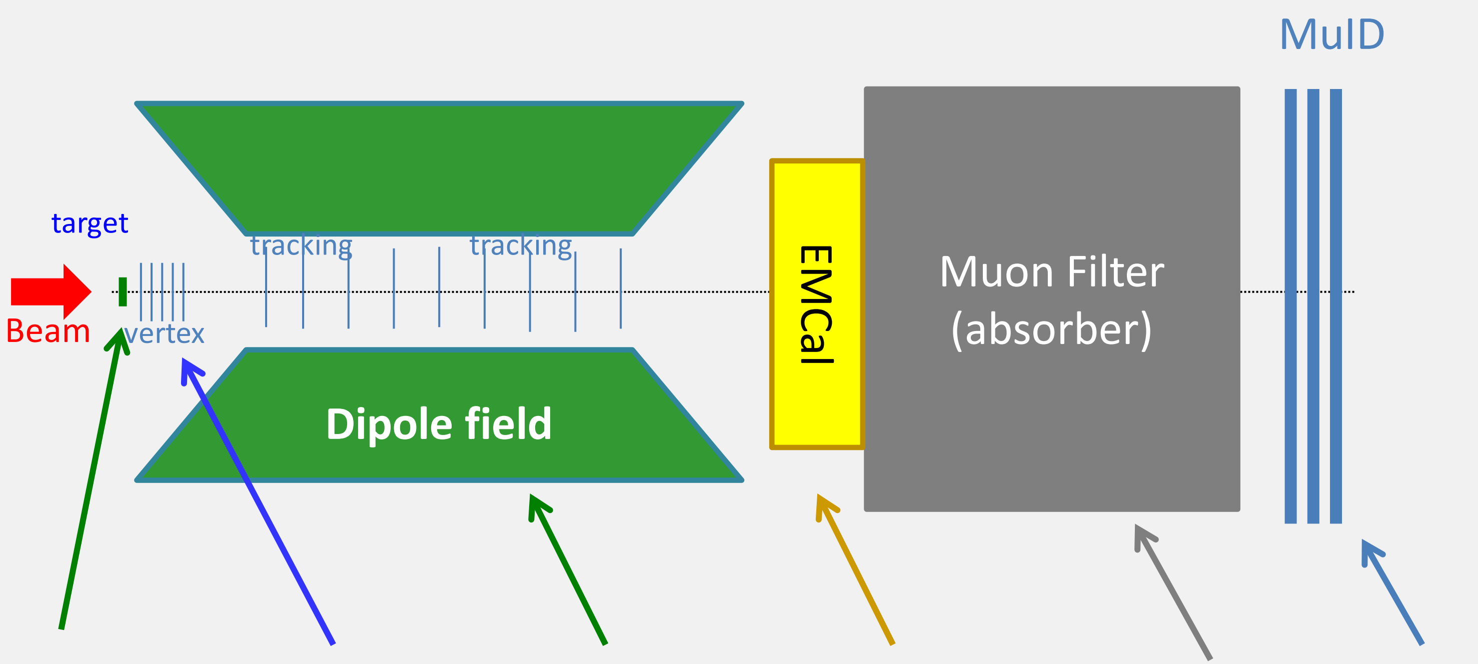
   what is the depence of charmonia suppression with rapidity @SPS energies?

   Crucial to understand effects due to cold nuclear matter

   Goal : measure charmonia within $y_{cms} \in [-0.5, 2]$

(See Tuesday talk)

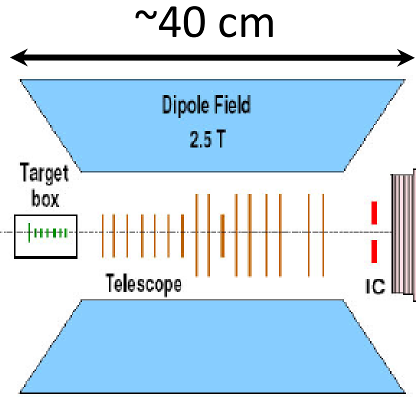
CHIC @ SPS – experimental setup



Active target → vertex → spectrometer → calorimeter → absorber → muID

CHIC @ SPS – Tracking

- **The NA60 pixel detector**



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

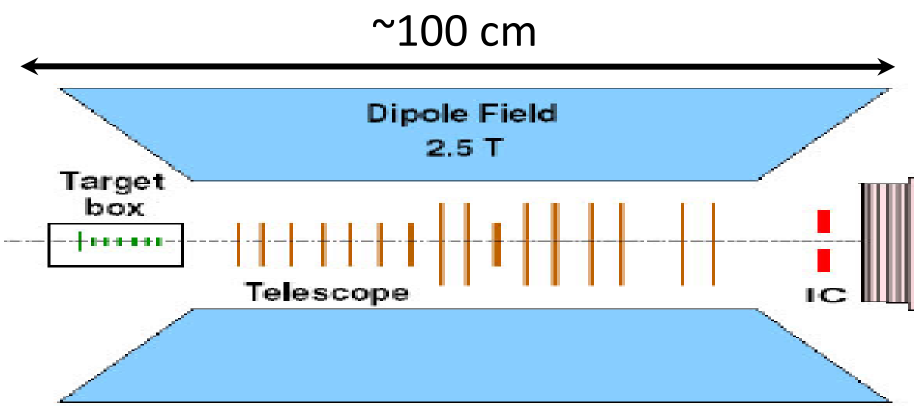
***L* = 0.4 m**

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

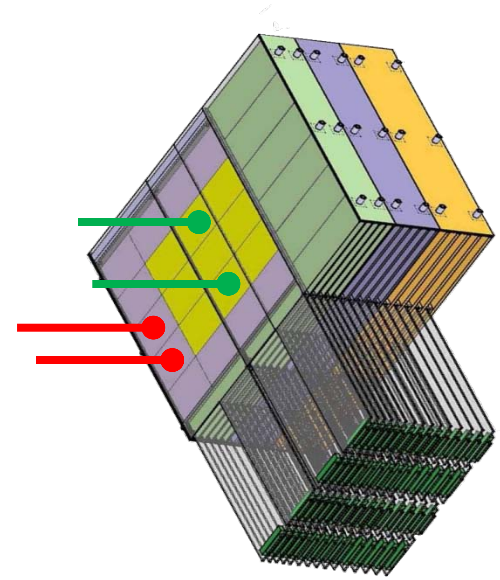
***L* = 1 m**

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

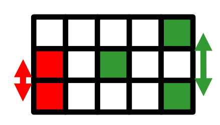
- **The CHIC pixel detector**



CHIC @ SPS – Calorimetry



- **Need very high segmentation**
  - Expect up to ~400 photons/rapidity unit
  - Need to separate two electromagnetic showers
  - Need 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
  - $\Delta E/E \sim 20\% / \sqrt{E}$
- **W+Si : two relevant quantities**
  - Distance between 2 incoming particles: at least one free pad



  - Moliere Radius

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

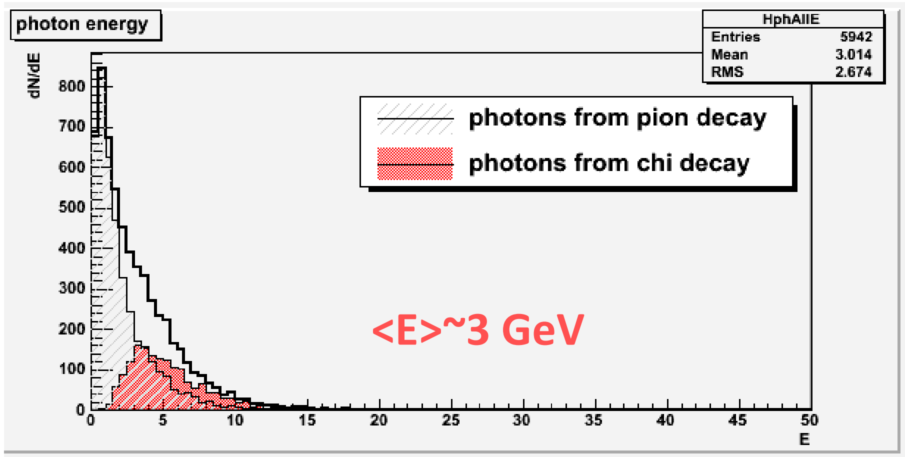
Geometrical condition: in principle
$\Delta\gamma > 2$cm

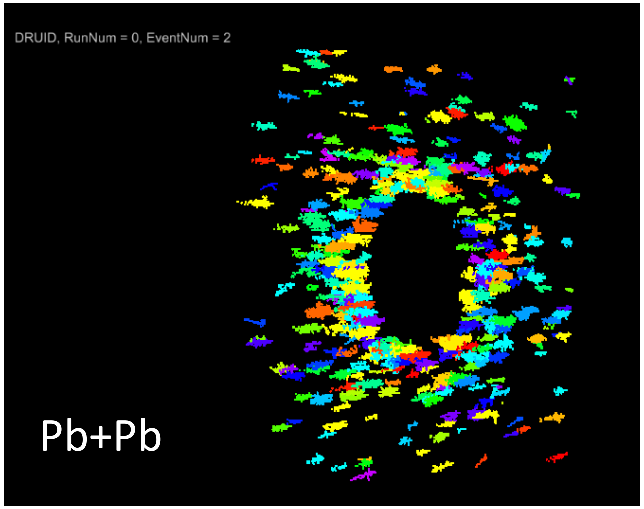
⇒

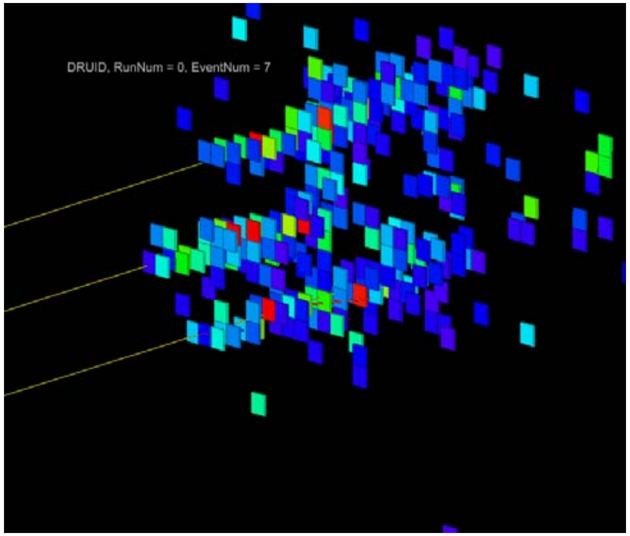
- Set detector position according to event multiplicity
- **at CHIC: z_{calo} ~ 2m**

CHIC @ SPS – 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.)

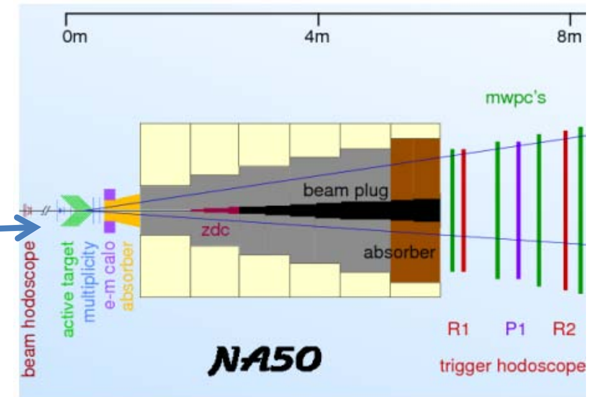
CHIC @ SPS – Absorber

- **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**

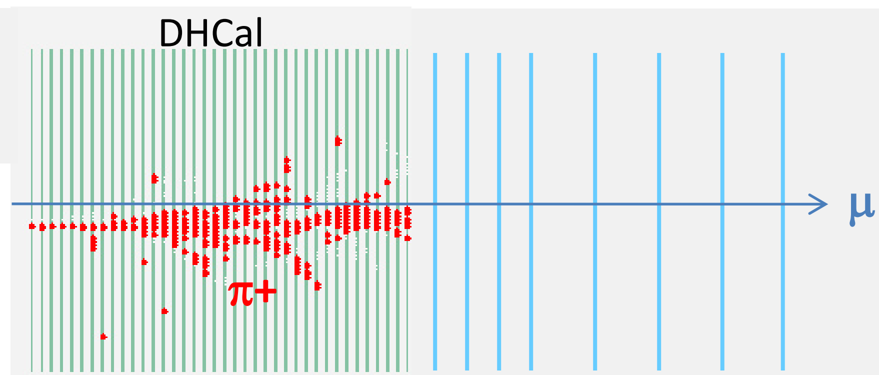


CHIC : measure muon momentum before the absorber

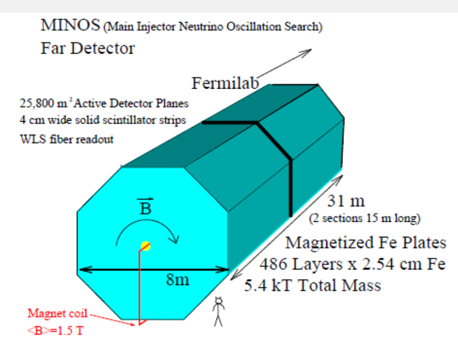
➔ minimization of multiple scattering not crucial

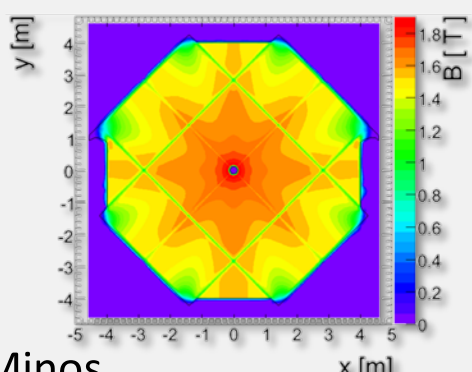
➔ **can use Fe material To absorb $\pi^{+/-}$**

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 @ SPS – Overall 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**

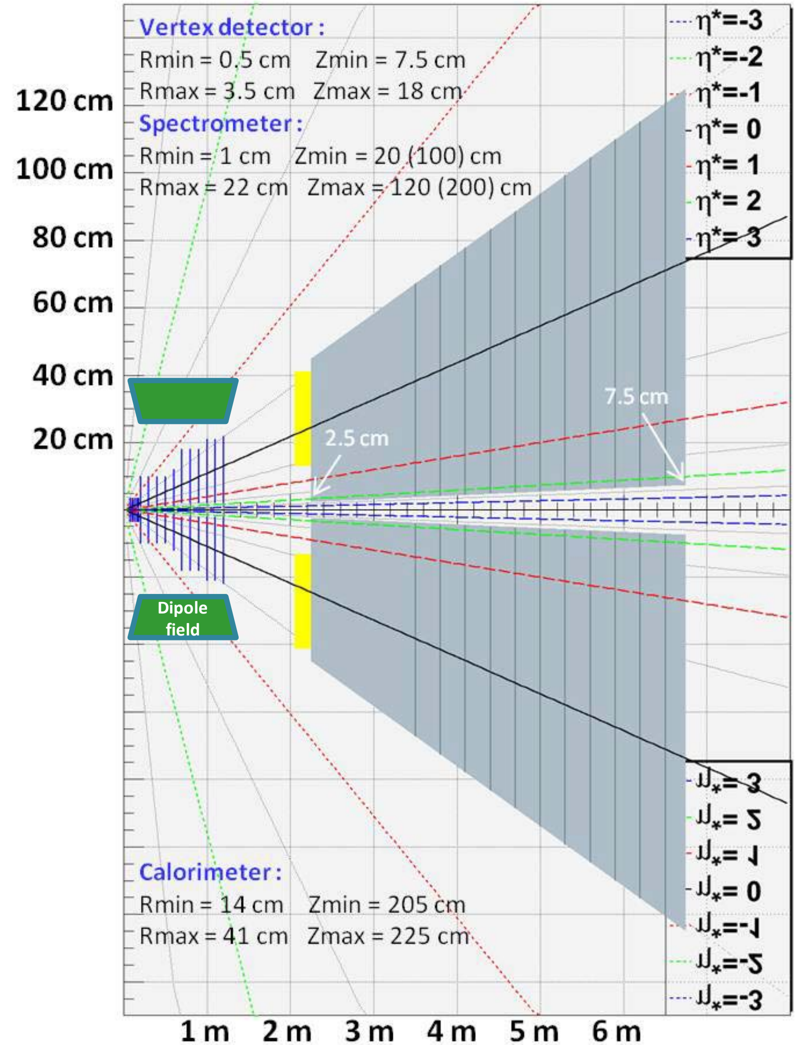
   - Using 4.5 m thick Fe to absorb π/K and low P $\mu^{+/-}$

   - Can use smaller absorber if Fe magnetized

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

- **Expected performances**

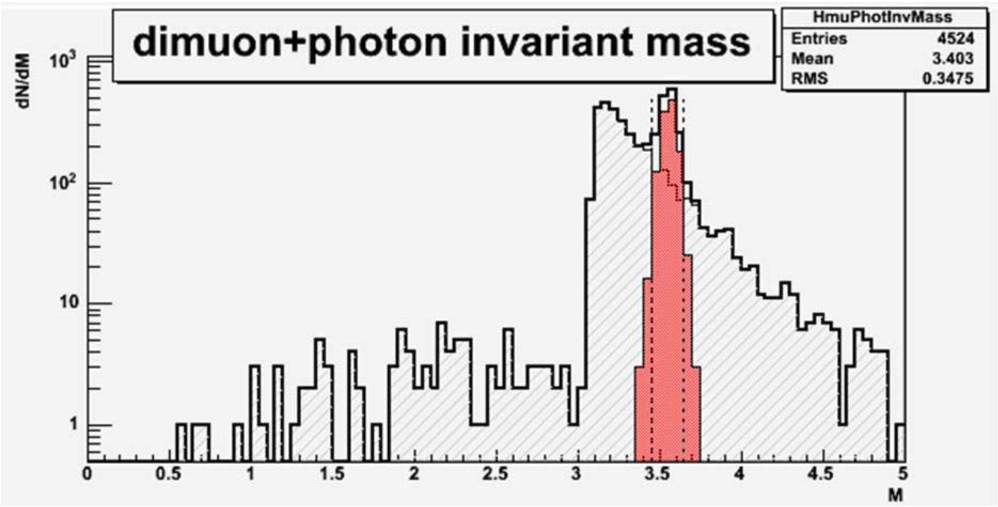
1. **tracking :** $\frac{\Delta P}{P} \sim 1\%$ within 1m long 2.5T $\vec{B}$
2. **Calorimetry :** $\frac{\Delta E}{E} \sim \frac{20\%}{\sqrt{E}}$

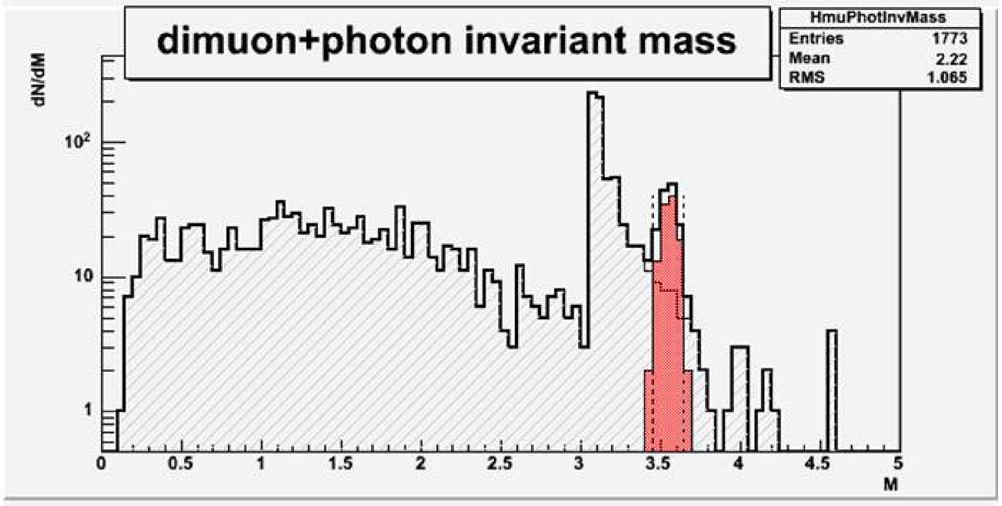


CHIC @ SPS – Performances

- χ_{c2} **in p+p collisions at $\sqrt{s}$=17.8 GeV**
  - **Sample:**
    - 20 kevents 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 kevents 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 hemisphere as J/Ψ
  - **Results** : signal/bkg = 3.6





AFTER/CHIC - Conclusion

- **CHIC :** (contact : F. Fleuret)
  - Very strong physics case : measure χ_c in Pb+Pb collisions @ SPS energies
  - not done in the 90's-00's because needed technologies not available at that time
  - Today, ultra-granular technologies are mature
  - Measuring χ_c in Pb+Pb collisions is now doable
  - Contact: F. Fleuret (fleuret@in2p3.fr) – LLR, Elena Ferreiro – Santiago

- **AFTER :**
  - Wider physics case (QCD at large x, nPDF, nuclear shadowing, QGP, spin physics)
  - Up to 7 TeV beam, very high boost, need ultra-granular technologies
  - Take advantage of the CHIC expertise to design AFTER
  - Contact: J.-P. Lansberg (lansberg@in2p3.fr) - IPNO, S. Brodsky – SLAC, F. Fleuret – LLR, C. Hadjidakis – IPNO

- **Timescale and plans :**
  - July 7th 2011 : one-day meeting
  - October 2011 :
    - Draft of a Letter Of Intent for CHIC to be submitted to SPS-C by the end of the year.
    - GDR-QCD meeting.
  - December 2011 : CHIC/AFTER ANR calls for proposal
    - simulations for CHIC (experimental)/AFTER (physics)
  - 2012 : AFTER expression of interest