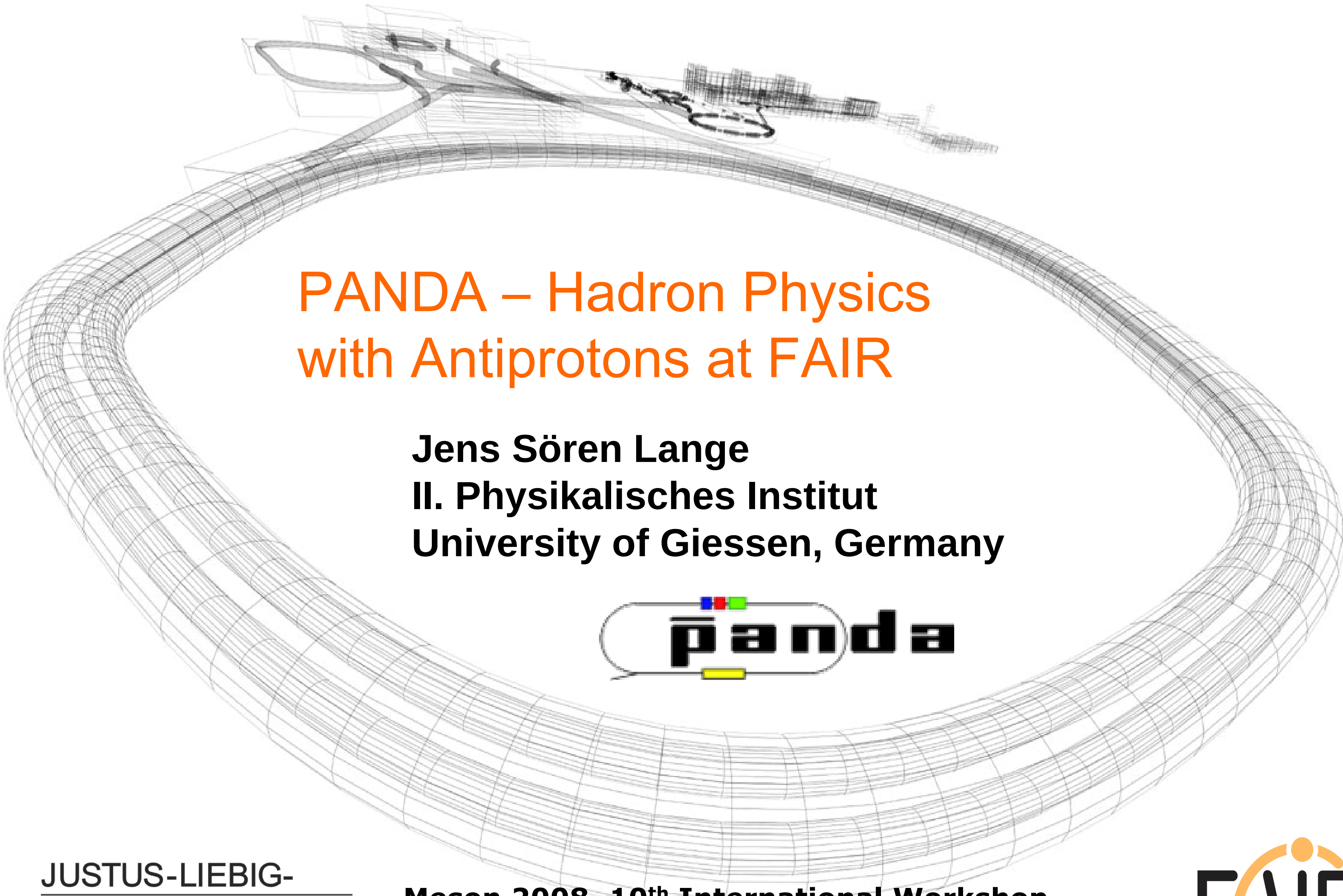


PANDA – Hadron Physics with Antiprotons at FAIR

Jens Sören Lange
II. Physikalisches Institut
University of Giessen, Germany

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

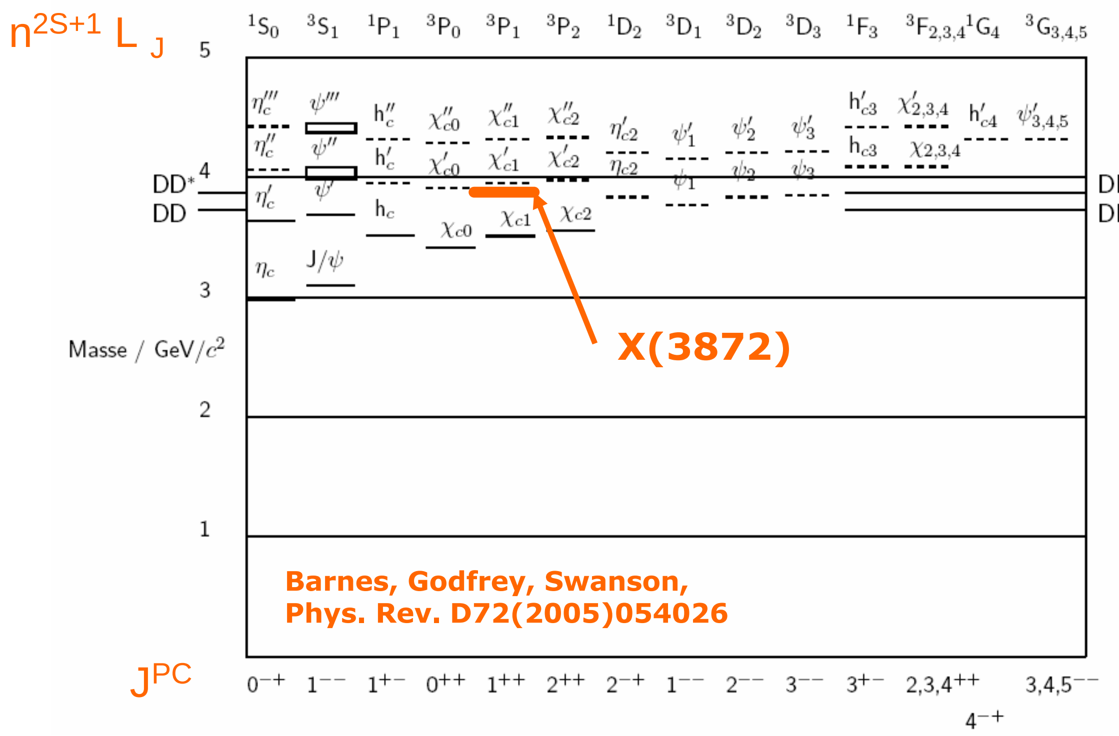
Meson 2008, 10th International Workshop on Meson Production, Properties and Interaction
Cracow, 6-10 June 2008

FAIR

Panda Physics Program

Charmonium spectroscopy

- „positronium of QCD"
- yet unobserved states above $\bar{D}D$ threshold
- XYZ states
- search for charmed hybrids ($\bar{c}cg$)

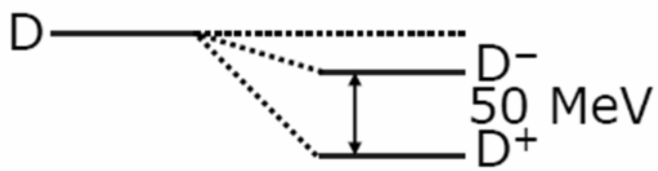


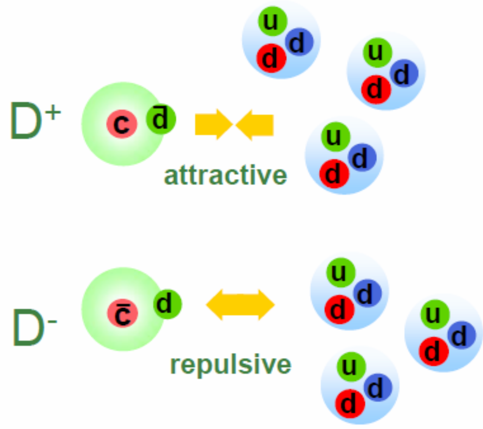
Charmed Meson Spectrocopy

- charmed meson spectroscopy
- D_{sJ}, chiral partners?
- search for tetraquarks

Charm in the Medium

- mesons in nuclear matter
- masses change in nuclei $\rightarrow$ mass(D) lower
- enhanced charmonium production due to lower $\bar{D}D$ threshold
- J/ψ absorption in nuclei



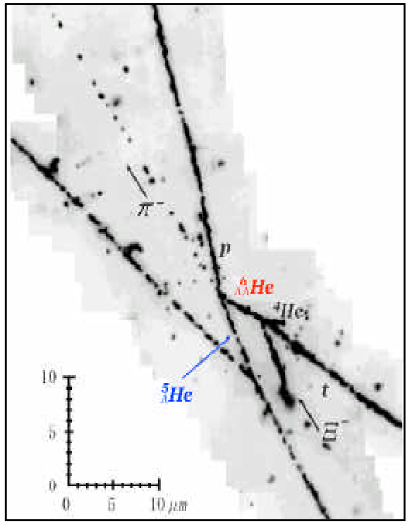


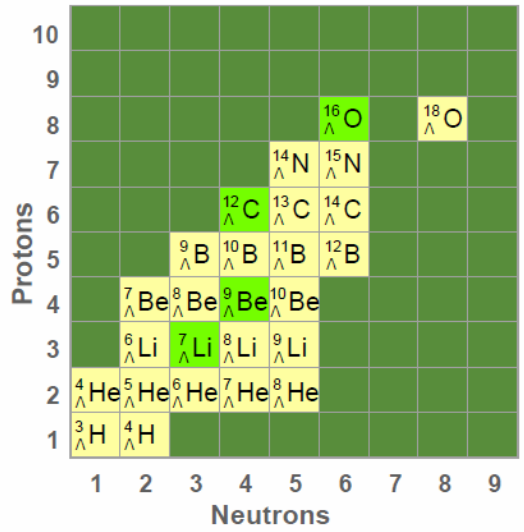
Panda Physics Program

Hypernuclei

- 3rd dimension in nuclear chart
  S=–2 Nuclei
- PANDA: Double Hypernuclei production via Ξ- capture
  ~50,000 stopped Ξ– per day
- Λ Λ interaction in nucleus

S=–2

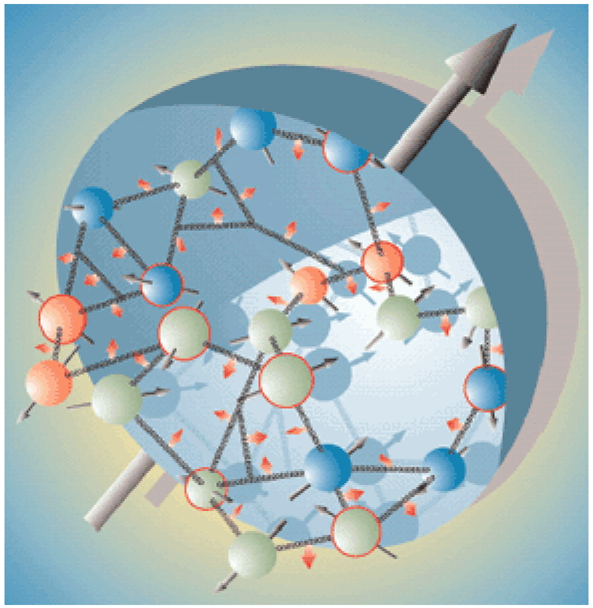


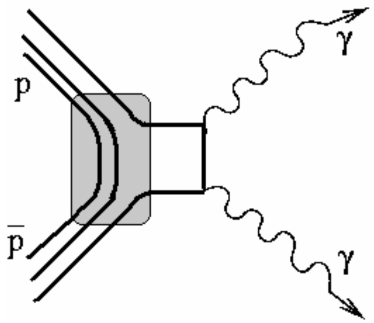


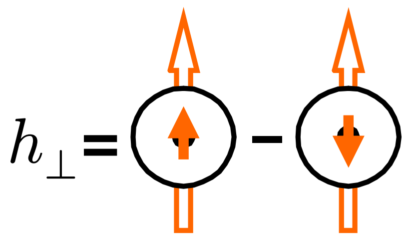
Electromagnetic formfactors
- timelike and spacelike region
- $p\ \bar{p} \rightarrow e^+e^-$
- see talk by Frank Maas, June 7, 09:00

Generalized Parton Distributions
- handbag diagrams
- $p\ \bar{p} \rightarrow \gamma\ \gamma^{(*)}$

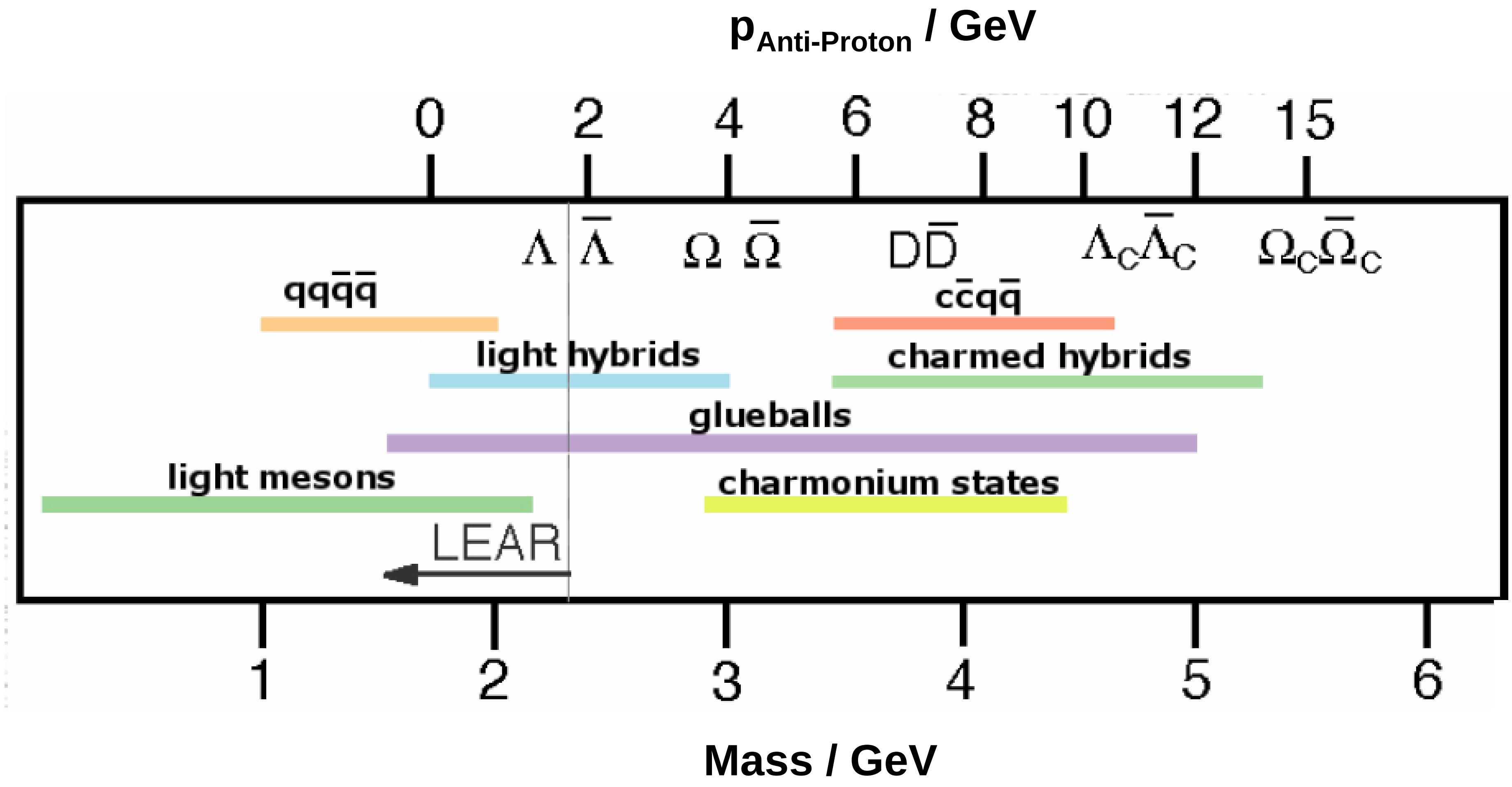
Transverse nucleon spin
- chiral-odd
- Drell Yan
- $p\ \bar{p} \rightarrow \mu^+\mu^-$ (X)
- proton tensor charge





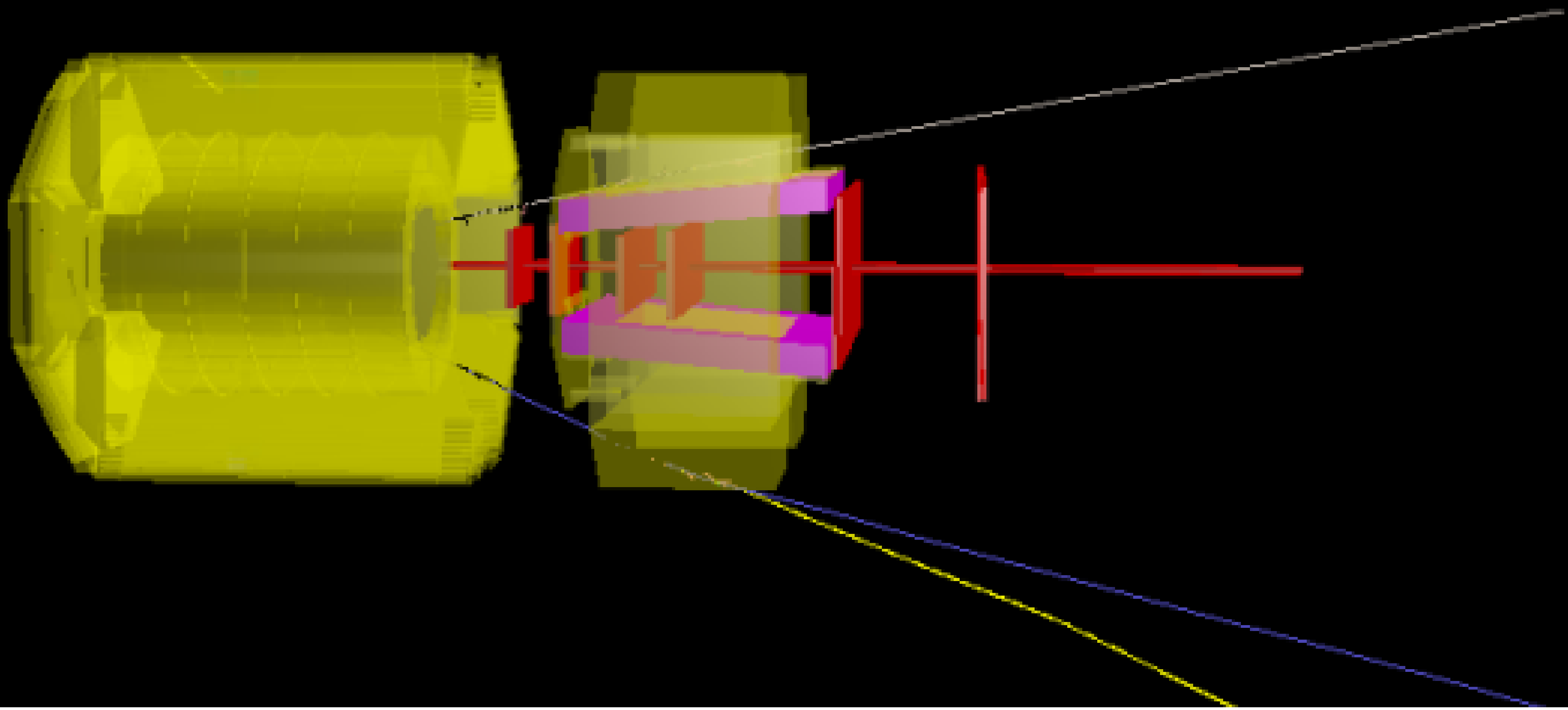


Panda Physics Program

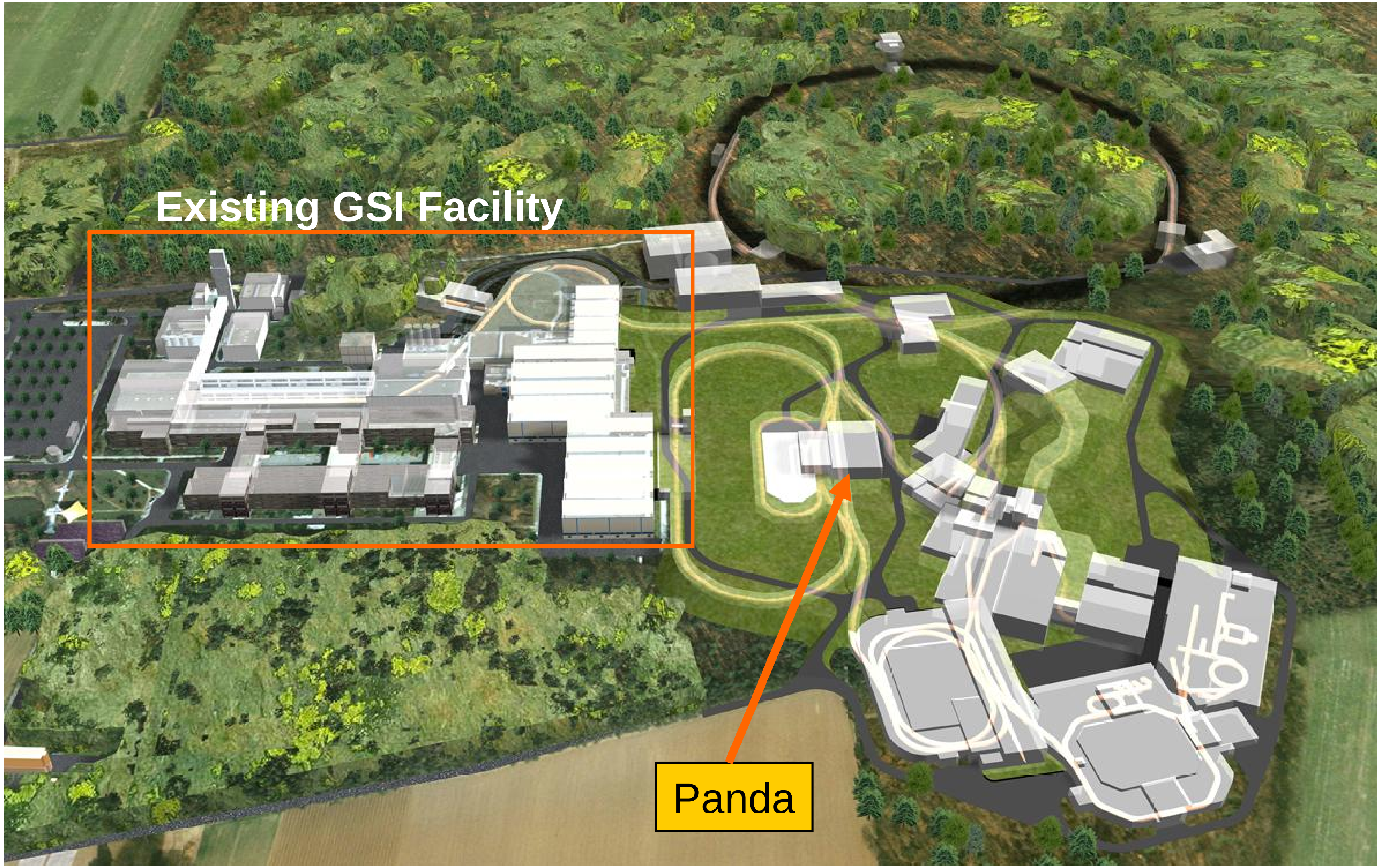


Outline

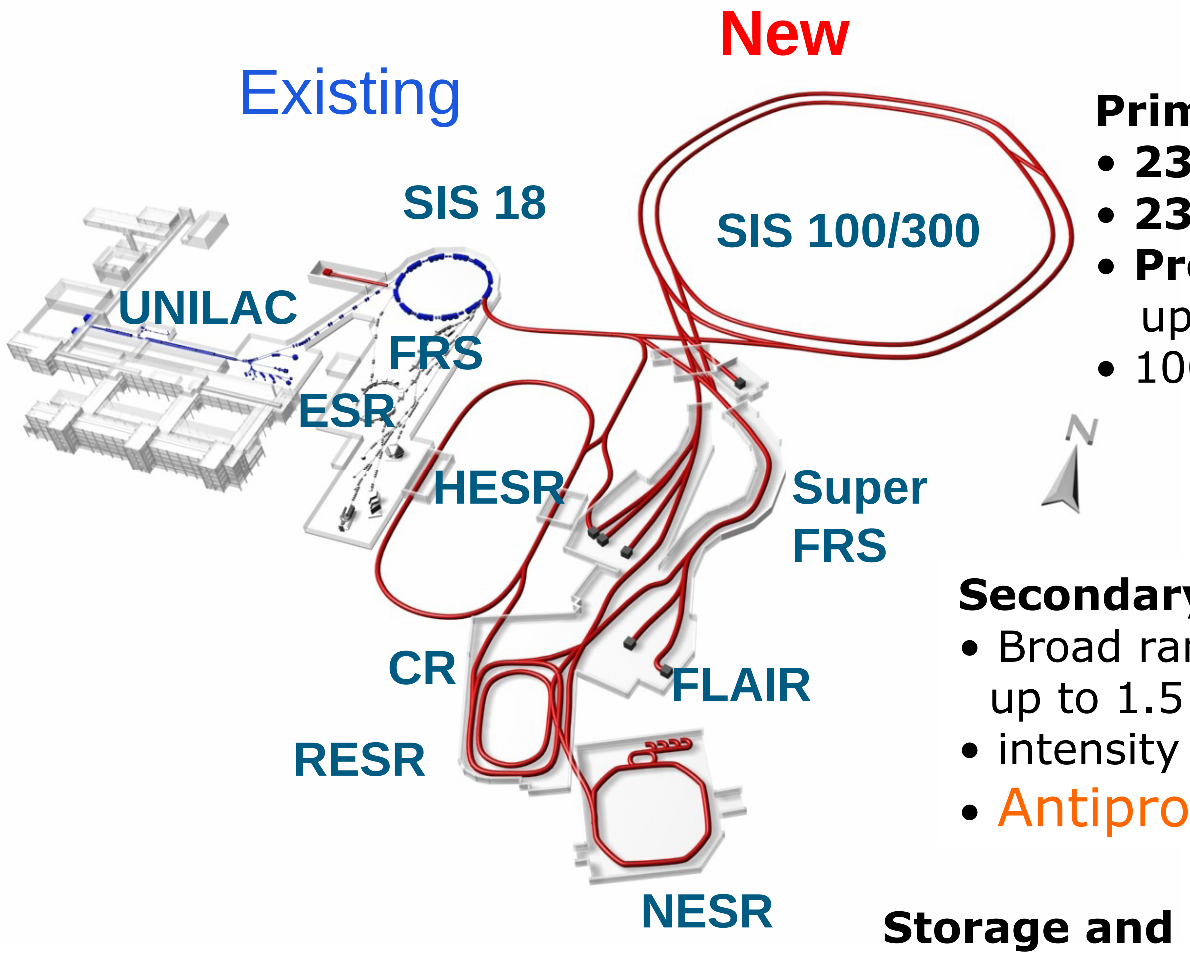
- The High Energy Storage Ring
- The Panda Spectrometer
- Physics Examples
  - Charmonium
    $\rightarrow$ X(3872)
  - Charmed Mesons
    $\rightarrow$ $D_{s0}(2317)$



FAIR, Facility for Antiproton and Ion Research
Darmstadt, Germany



FAIR



Primary Beams

- **238U^{28+}** : 10^{12}/s @ 1.5-2 AGeV
- **238U^{92+}**: 10^{10}/s @ <35 AGeV
- **Protons** : 2 x10^{13}/s @ 30 GeV
  up to 90 GeV
- 100-1000x present intensity

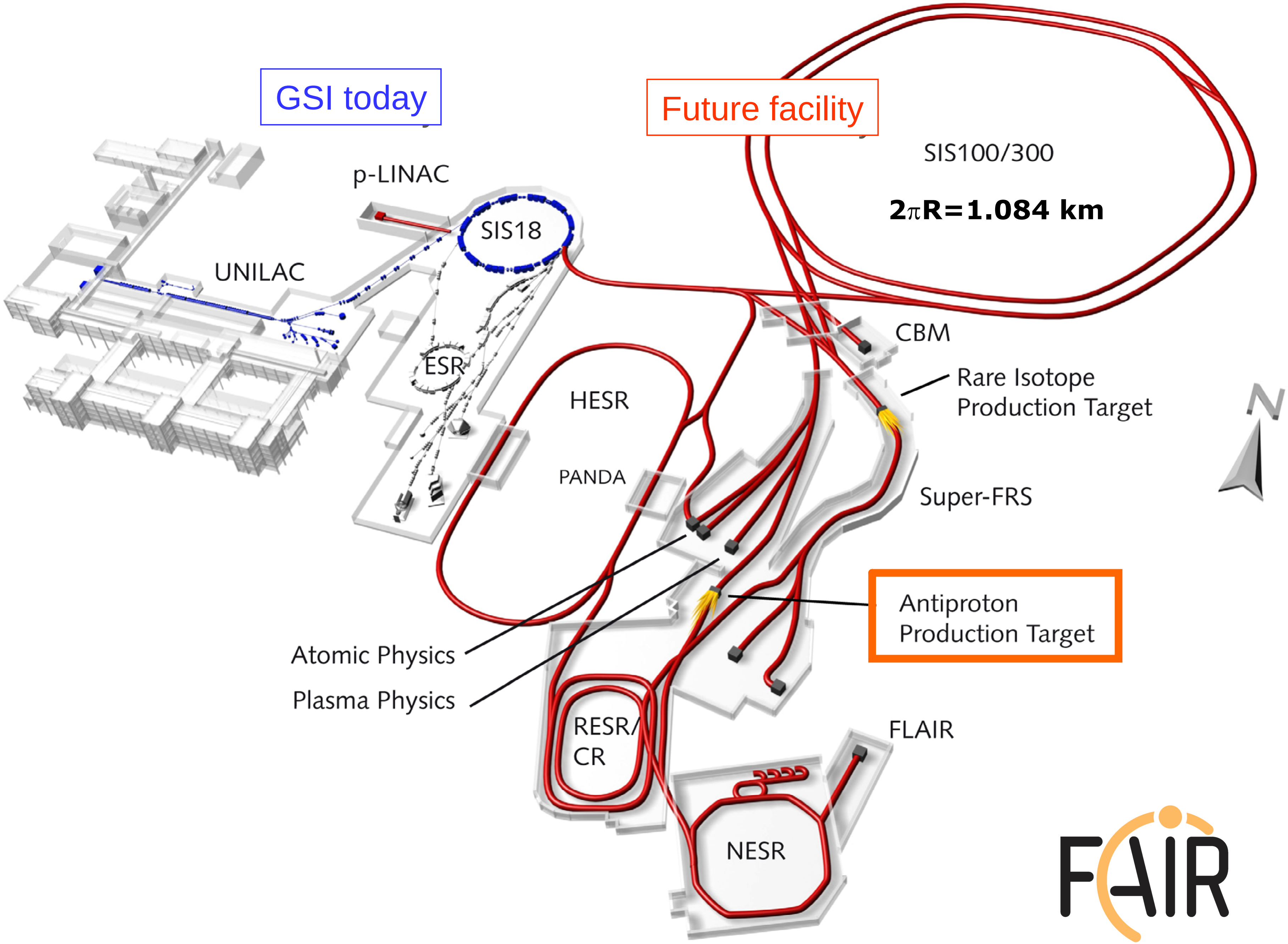
Secondary Beams

- Broad range of radioactive beams
  up to 1.5 - 2 AGeV
- intensity up to 10000x over present
- Antiprotons 1 - 15 GeV

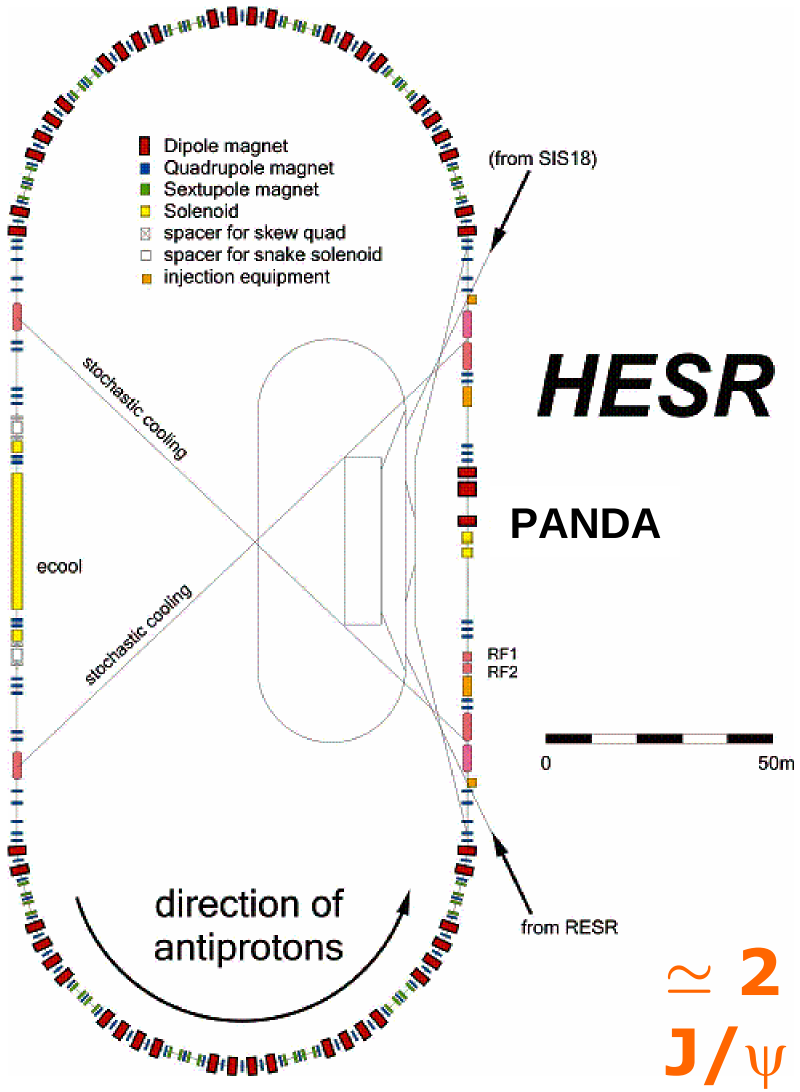
Storage and Cooler Rings

- Radioactive beams
- 10^{11} stored and cooled Antiprotons
  0.8 - 14.5 GeV/c in HESR

- Cooled beams
- Parallel Operation


GSI today
Future facility
p-LINAC
SIS18
UNILAC
ESR
SIS100/300
2πR=1.084 km
CBM
Rare Isotope
Production Target
HESR
PANDA
Super-FRS
Antiproton
Production Target
Atomic Physics
Plasma Physics
RESR/
CR
FLAIR
NESR
FAIR

HESR (High Energy Storage Ring)



For Anti-Protons

High intensity mode

- $10^{11}\ \bar{p}$
- $\delta p/p \approx 10^{-4}$ (stochastic cooling)

High resolution mode

- $10^{10}\ \bar{p}$
- $\delta p/p \approx 10^{-5}$ (e^- cooling)

Internal targets

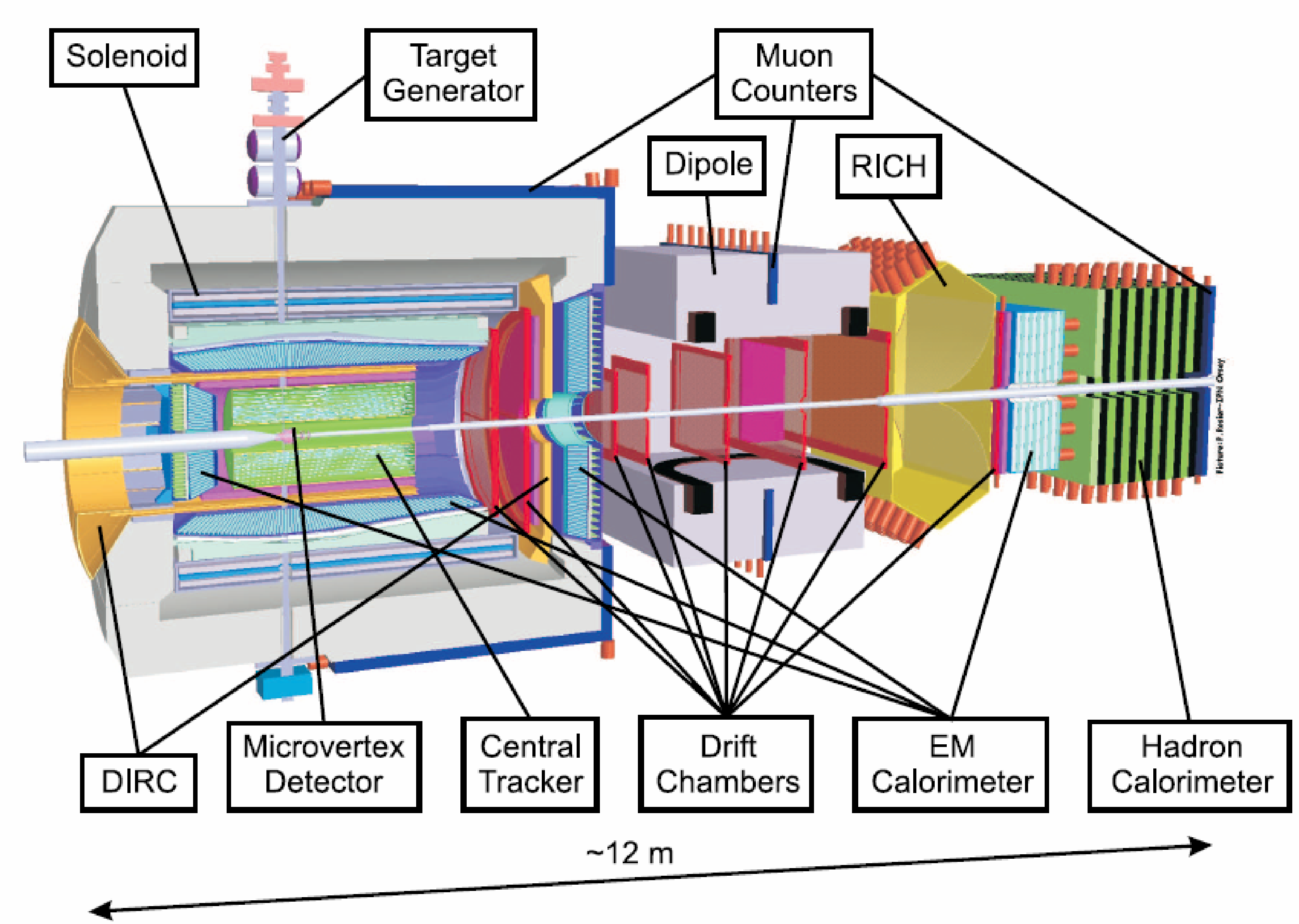
- $\mathcal{L} = 2 \cdot 10^{32}\ \mathrm{cm^{-2}s^{-1}}$
- Pellets
- Cluster jet
- Nuclei: Be, C, Si, Al

$\simeq$ 2 x 10^9 J/ψ per year

Detector Requirements

- **High rates**
  $2 \cdot 10^7$ interactions / s
- 4π **solid angle**
- **Vertex detection:** *D*, Λ, K_S^0, ...
  $\sigma_v < 100 \mu m$
- **Momentum resolution**
  $\delta p/p \sim 1\%$
- **Charged particle ID**
  $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, K, p
- **Electromagnetic calorimetry**
  10 MeV $< E_\gamma <$ 5 GeV
- **Efficient event selection**

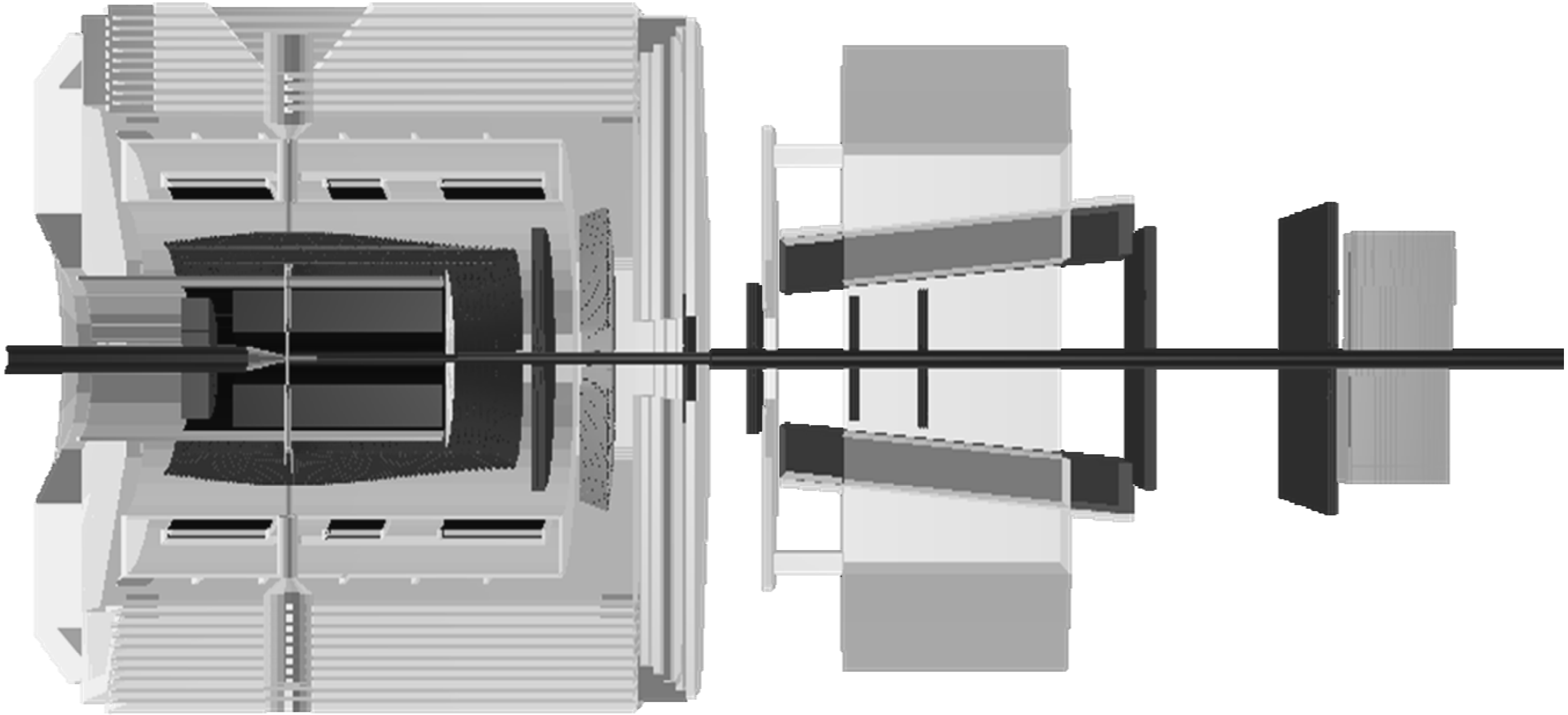
The Panda Spectrometer



Target Spectrometer
Solenoid B_z=2 T

Forward Spectrometer
Dipole B·L=2 Tm

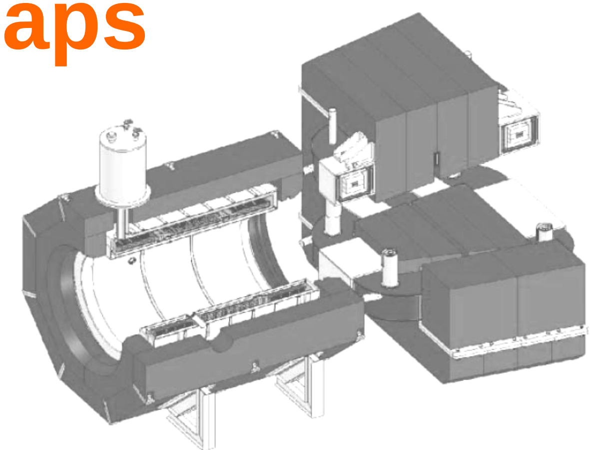
The Panda Spectrometer
Implementation in Monte-Carlo Simulation



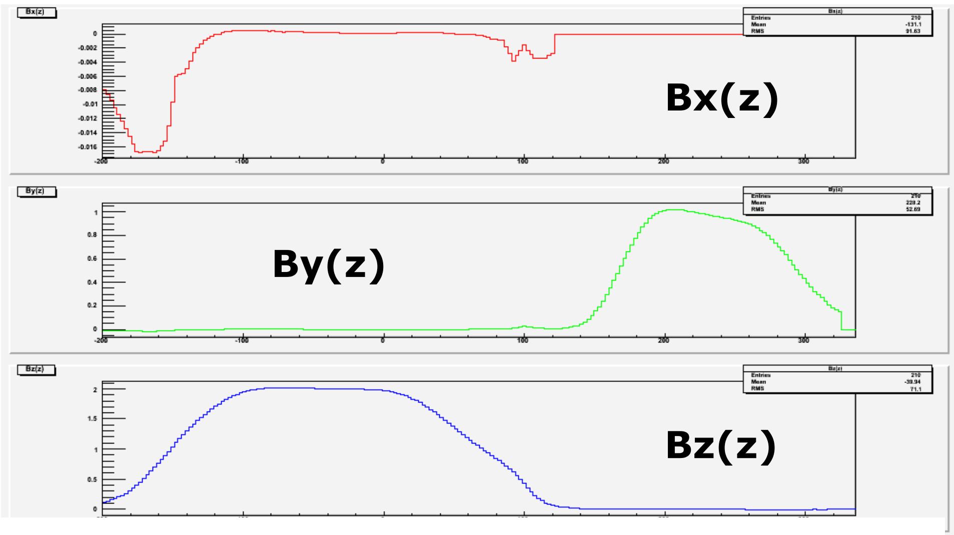
43,000 geometry volumes
~400,000 lines of C++ code
Geant3, Geant4, FLUKA
digitization, reconstruction, analysis

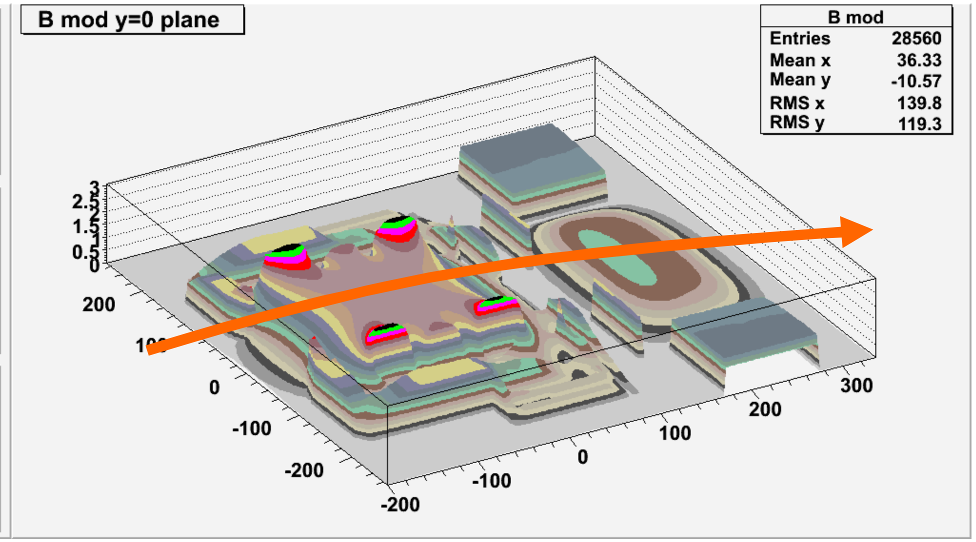
$\geq$ 20 programmers/developers
$\leq$ 20 Linux platforms
$\geq$ 1 TB data generated on GRID
Framework PandaRoot

B Field Maps



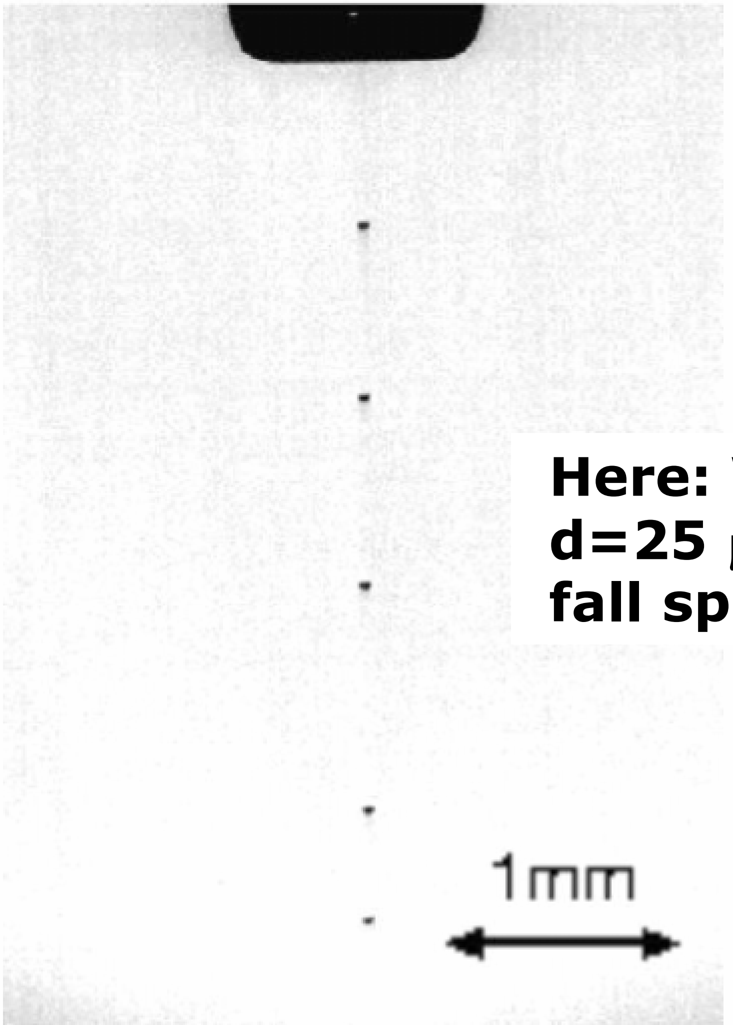
B field in kG





→ beam deflection for p_{beam}=15 GeV/c 4.2 cm @ z=6m (end of dipole)

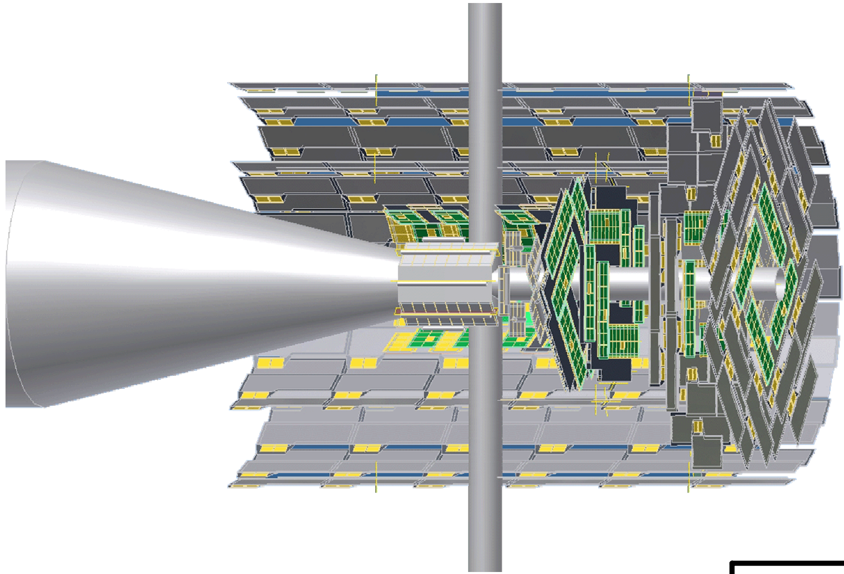
The Pellet Target

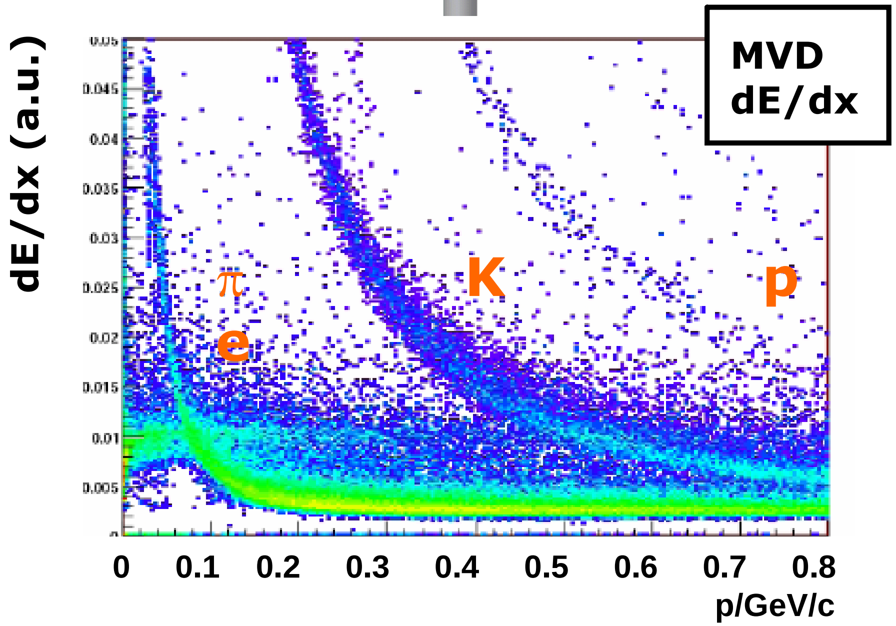


Here: WASA Target
d=25 μm
fall speed $\geq$ 60 m/s

MVD (Micro Vertex Detector)

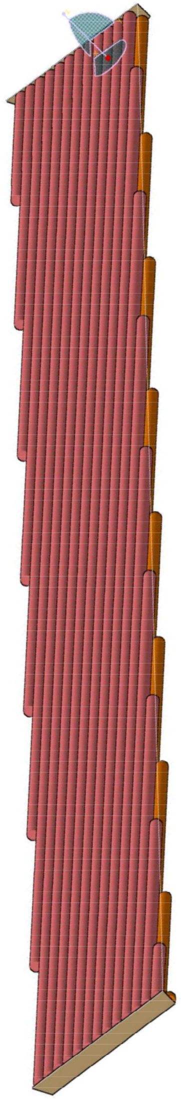
- **4 barrels & 8 disks**
  - inner layers pixels
  - outer layers strips
  - forward mixed
- **Silicon Pixel Detectors**
  - 120 modules
  - 100x100 μm^2 pixel size
  - ~10^7 readout channels
  - maximum rate <10 MHits s^{-1} per module
  - Radiation length ~1% X_0 per layer
- **Silicon Strip Detectors**
  - 400 modules
  - ~0.5 m^2 active area
  - $7x10^4$ readout channels

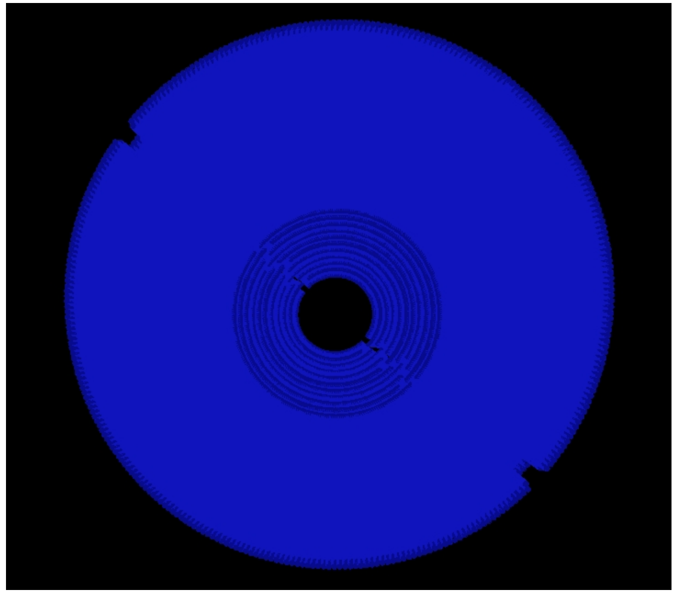


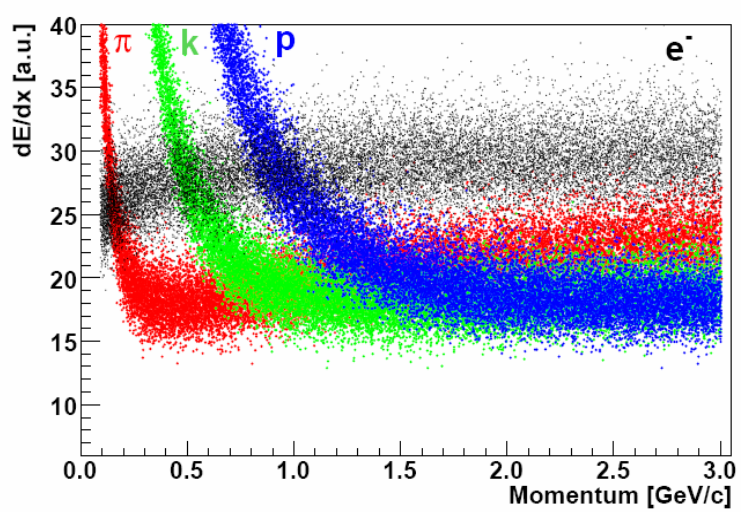


STT (Straw Tube Tracker)

- ~4100 tubes, axial or skewed (15 double layers)
- R=15.5-41.5 cm
- L=1.5m
- (only) m=50 kg
- tube diameter 10mm wall Mylar, 30µm
- anode wire W/Re, 20µm
- spatial resolution
  $\sigma_{r\varphi}$ ~ 150µm (axial layers)
  s_z ~ 3-10mm (skewed layers)
- gas 90%Ar,10%CO_2 over-pressure for stabilization p=2 bar
- radiation length ~1-1.3% X_0
- wire U=2 kV
- $\delta p_T/p_T \simeq 1.2\%$
- prototype under investigation

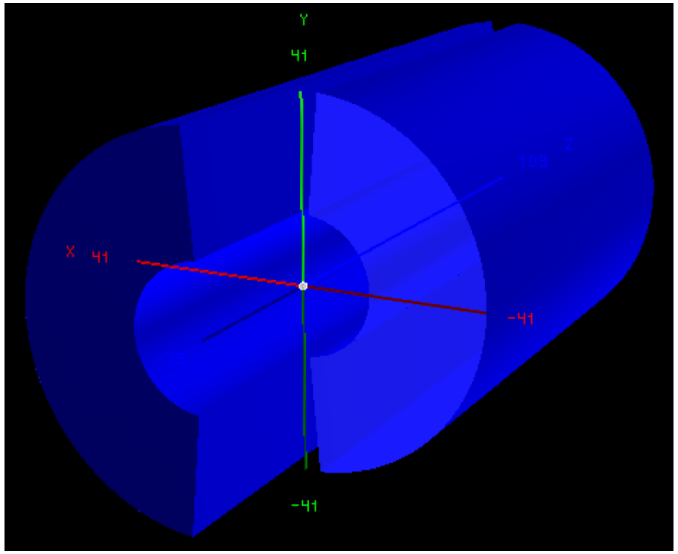


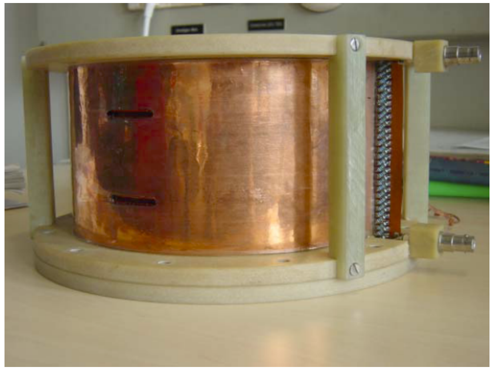


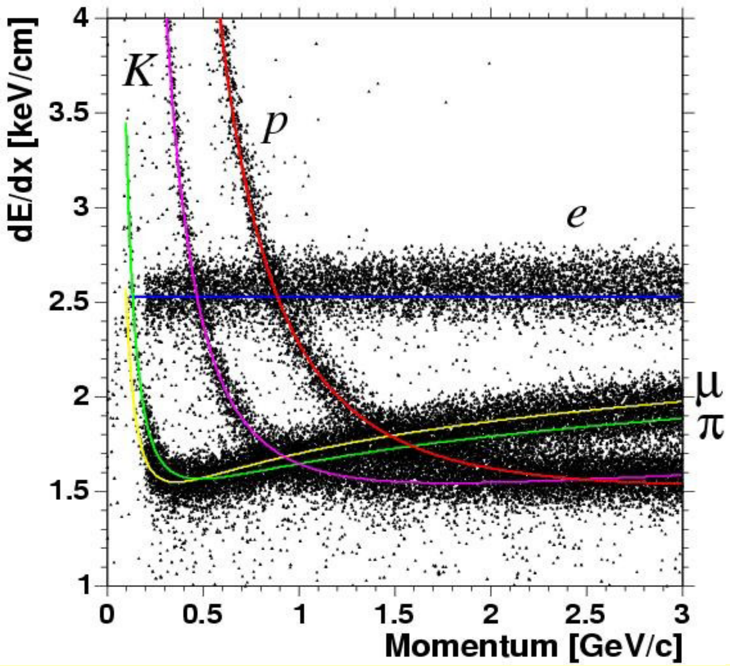


TPC (Time Projection Chamber)

- R=15.5-41.5 cm
- 135 padrows
- 135,169 pads of 2x2 mm^2
- Multi-GEM for amplification and ion backflow suppression
- Gas: Ne/CO_2 ($+CH_4/CF_4$)
- 50-70 µs drift time $\rightarrow$ 700 events pile-up
- **gating grid continously open**
- $\delta p/p \simeq 1\%$
- prototype under investigation







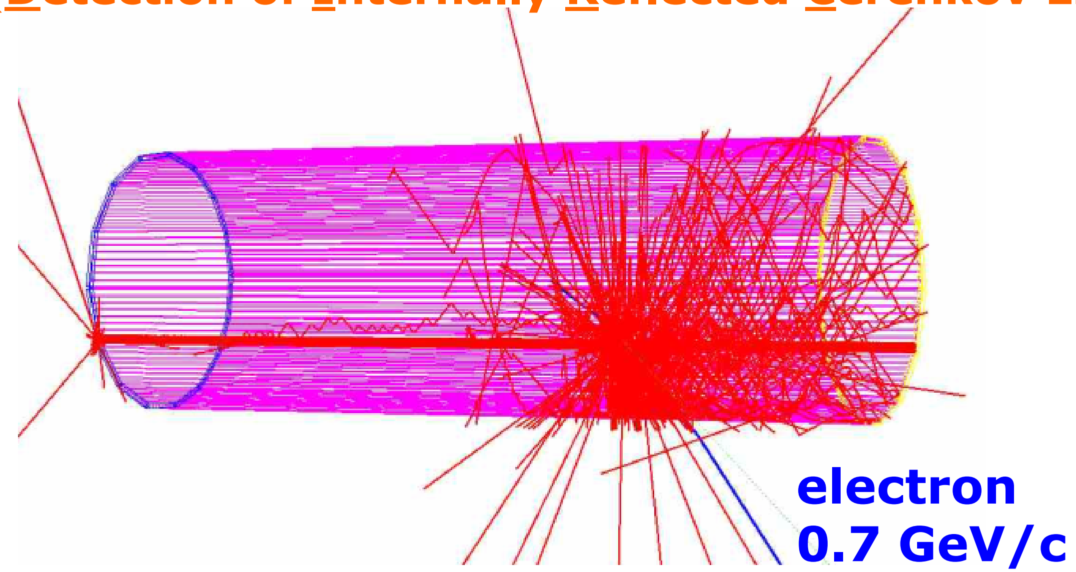
DIRC

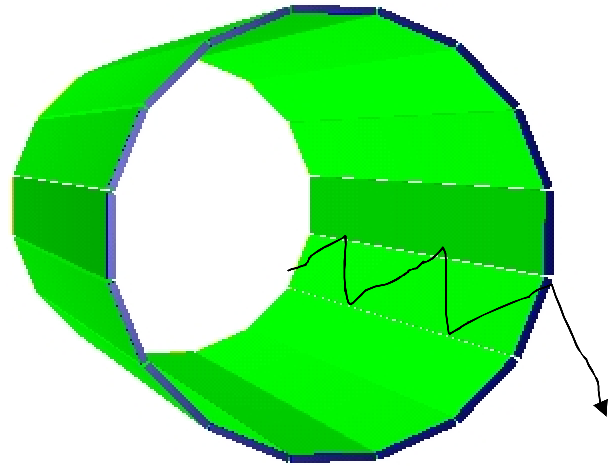
(Detection of Internally Reflected Cerenkov Light)

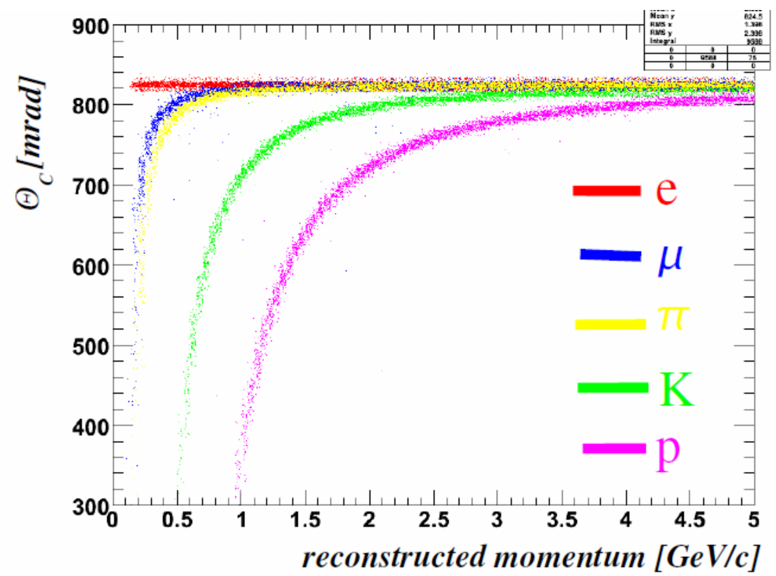
16 Quartz (n=1.47) Bars

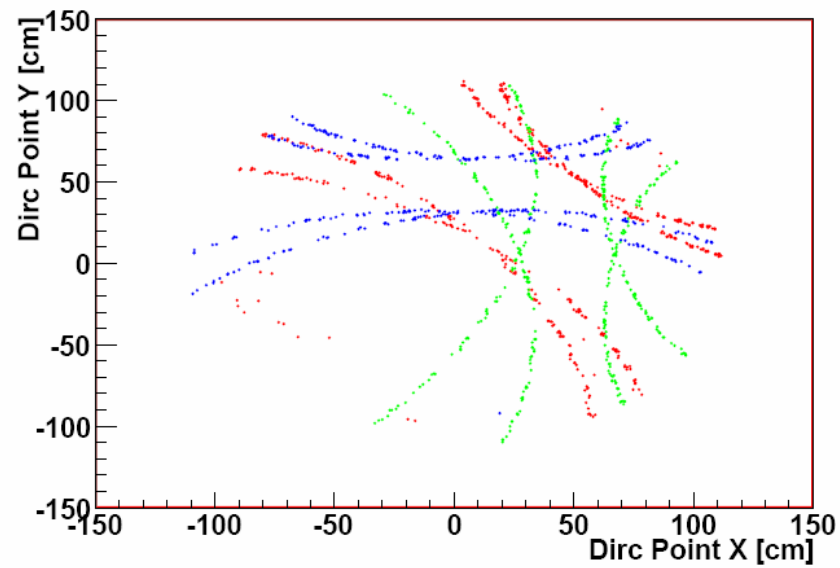
d=1.7 cm, R=48 cm

BaBar design



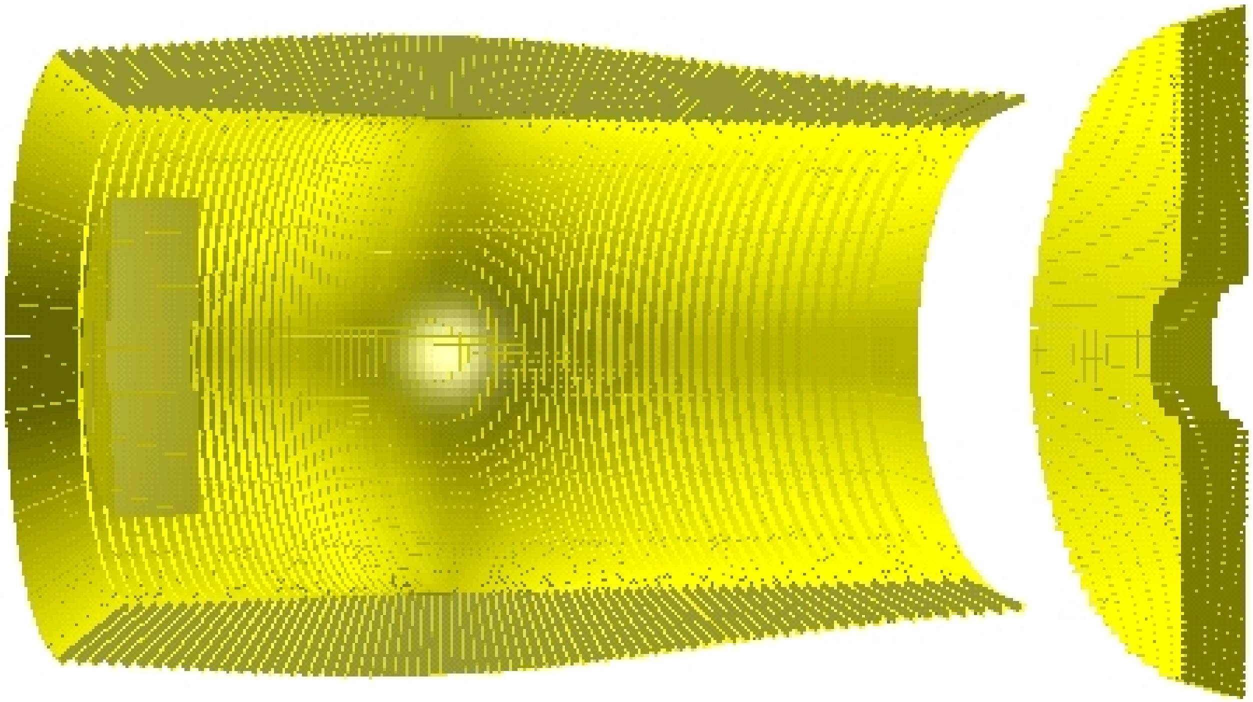






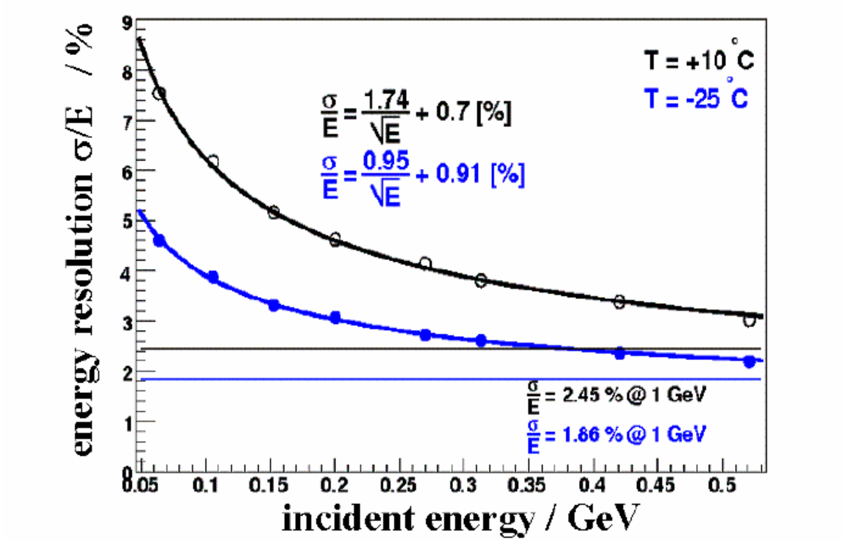
EMC (Electromagnetic Calorimeter)

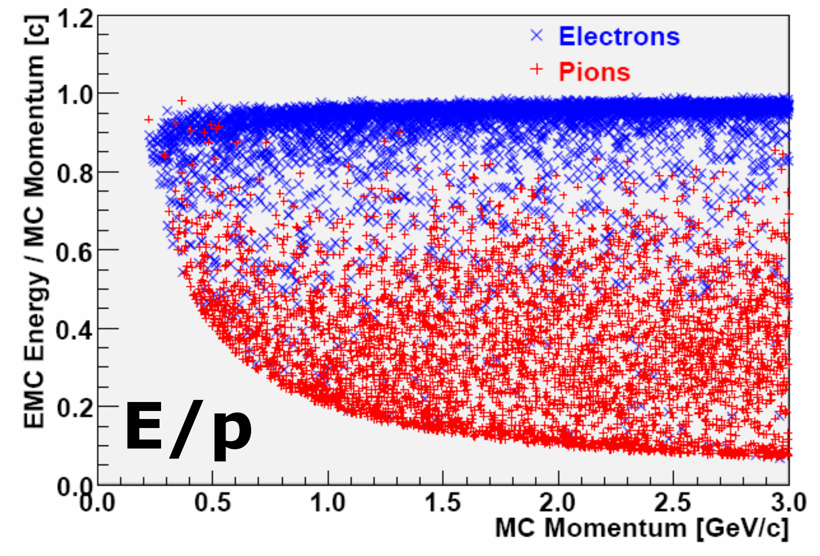
~17,200 crystals
$PbWO_4$ (radiation hard, fast τ_{Decay}~6 ns)
28 X_0
dE/dx=13.0 MeV/cm

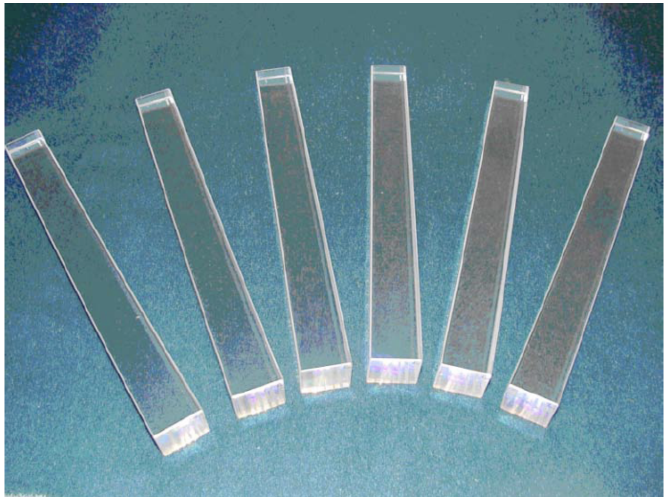


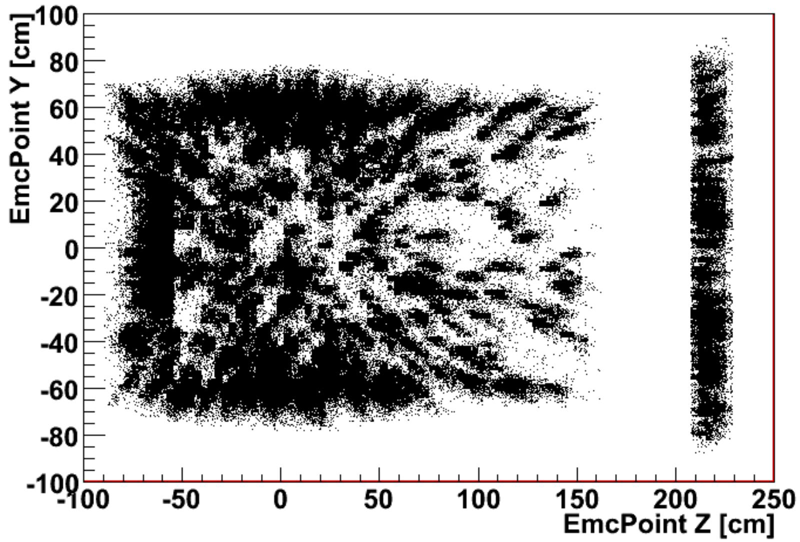
EMC (Electromagnetic Calorimeter)

operated at T=–25° C



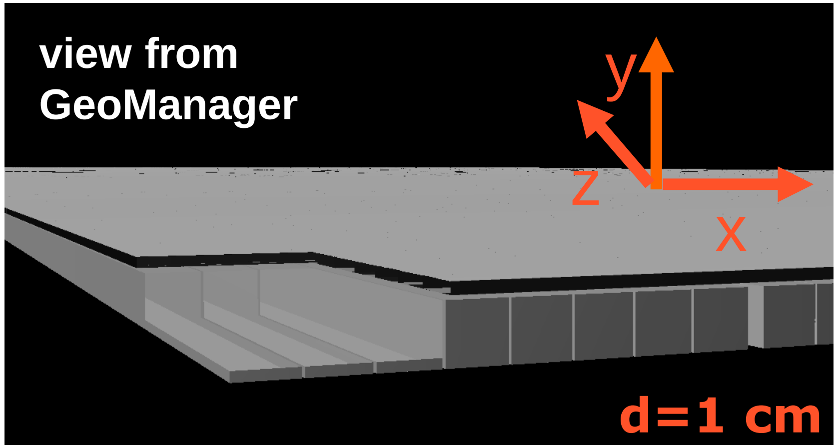


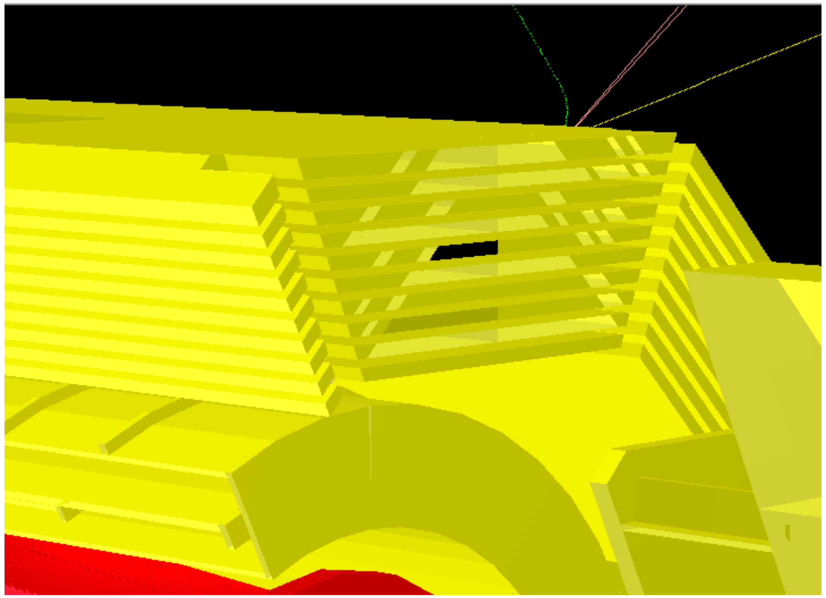


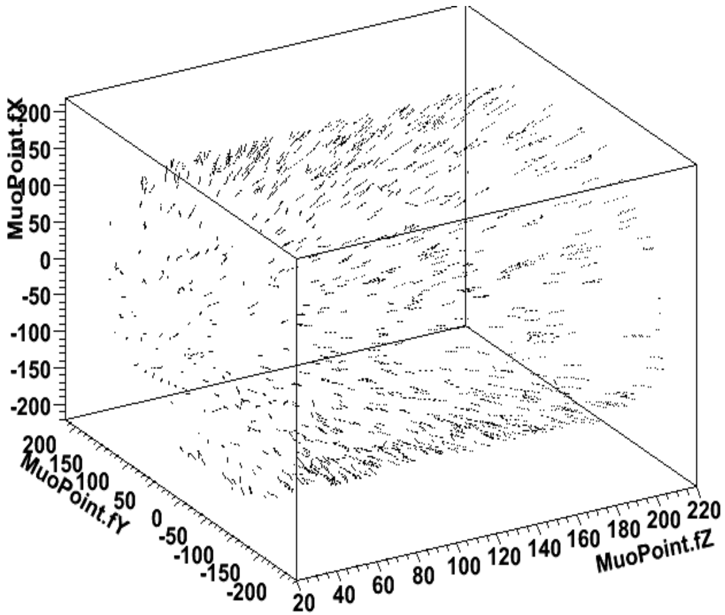


MUO (Muon Detector)

- R = 1.3−1.8 m
- tubes (for x coordinate)
  gold plated tungsten wire,
  d=0.05 mm, L=4 m,
  wire U=+3.6 kV, cathode U=-1.2 kV
- copper strips (for z coordinate)
  U=+1.8 kV
- $\rightarrow$ pad size 1x1 cm^2





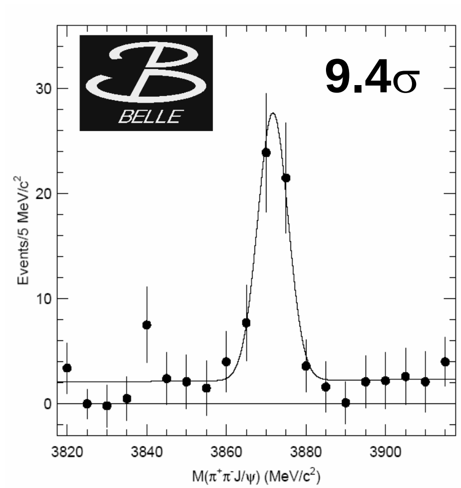


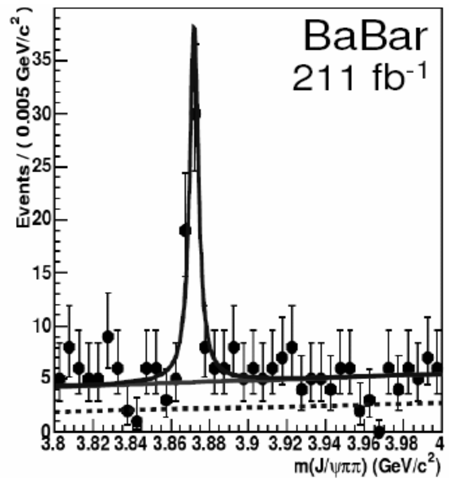
Panda Physics Example #1:

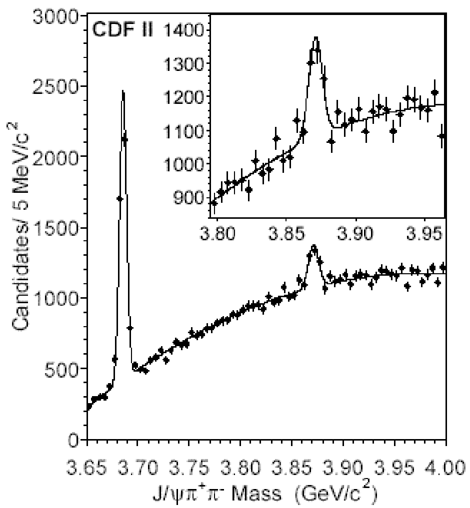
Charmonium
X(3872)

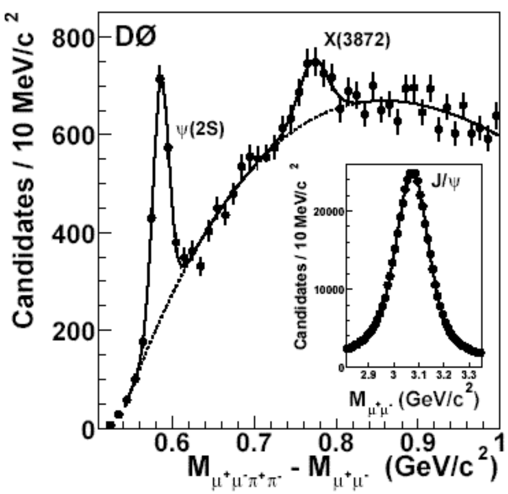
X(3872) – a New Charmonium State

- C=+1
  $\rightarrow$ can **not** be produced
  in e^+e^- formation
  $\rightarrow$ unique for Panda
- does **not** fit into potential model
- mass within 1 MeV of $\bar{D}D^*$ mass
  $\rightarrow$ molecule?
  $m \simeq 2m_{deuteron}$
- binding energy small
  radius estimate
  E=0.6 MeV $\rightarrow$ **$\langle r \rangle = 2.9^{+\infty}_{-0.9}$ fm**
  Braaten, QWG 2007
  (average, not tail)





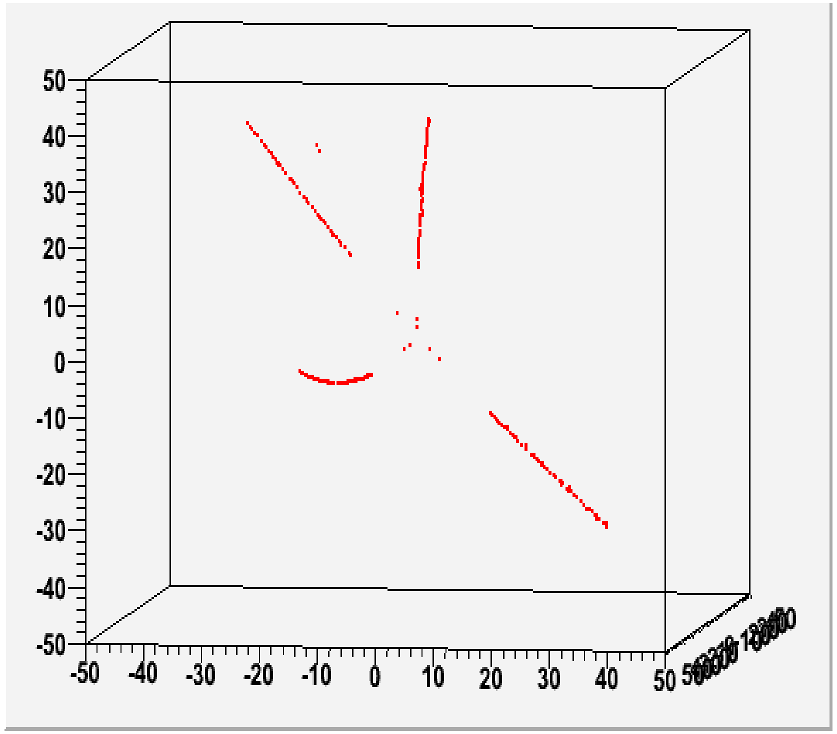


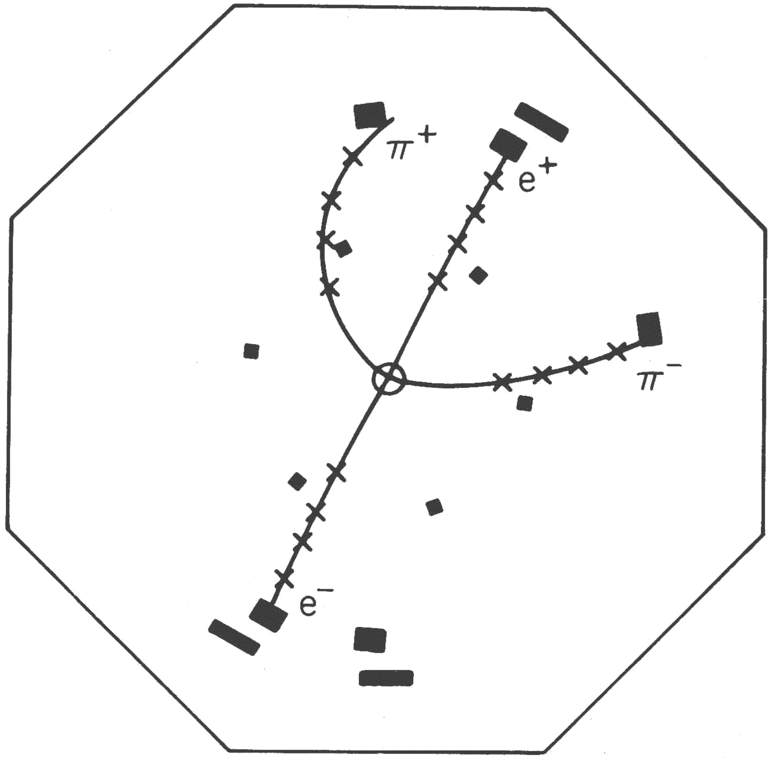


Belle, Phys. Rev. Lett.91(2003)262001
CDF-II, Phys. Rev. Lett.93(2004)072001
D0, Phys. Rev. Lett.93(2004)162002
BaBar, Phys. Rev. D71(2005)071103

X(3872) Events in Panda

XYZ coordinates / cm



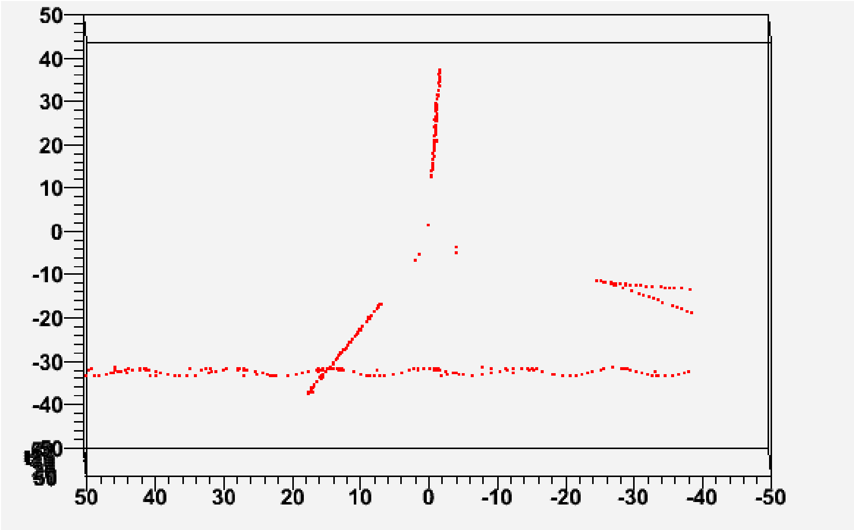


PandaRoot Simulation
X(3872) $\rightarrow$ J/ψ π^+ π^-
TPC digitization, MVD digitization

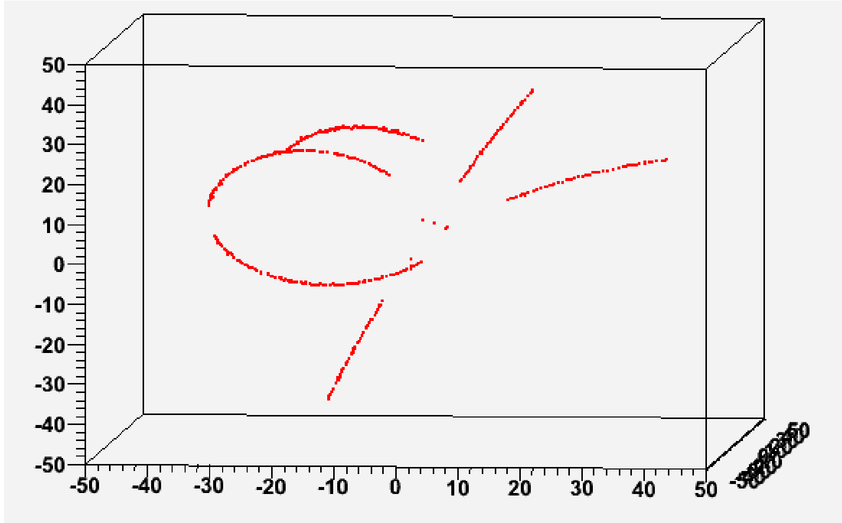
ψ' $\rightarrow$ J/ψ π^+ π^-
Mark II Experiment, 1973

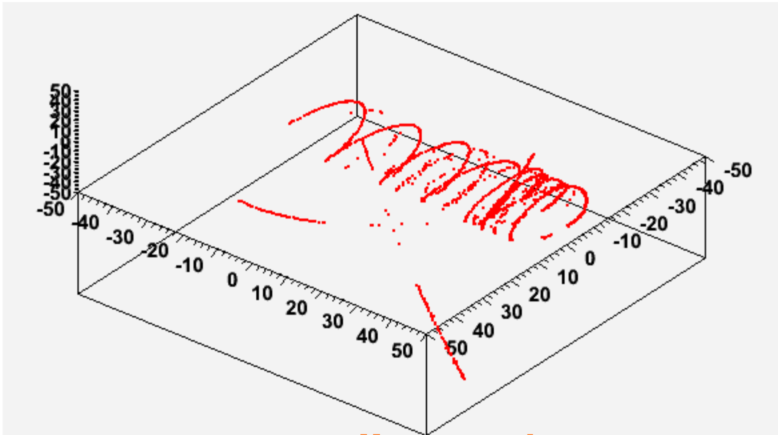
X(3872) Events in Panda MVD+TPC
PandaRoot Simulation

XYZ coordinates / cm



XYZ coordinates / cm





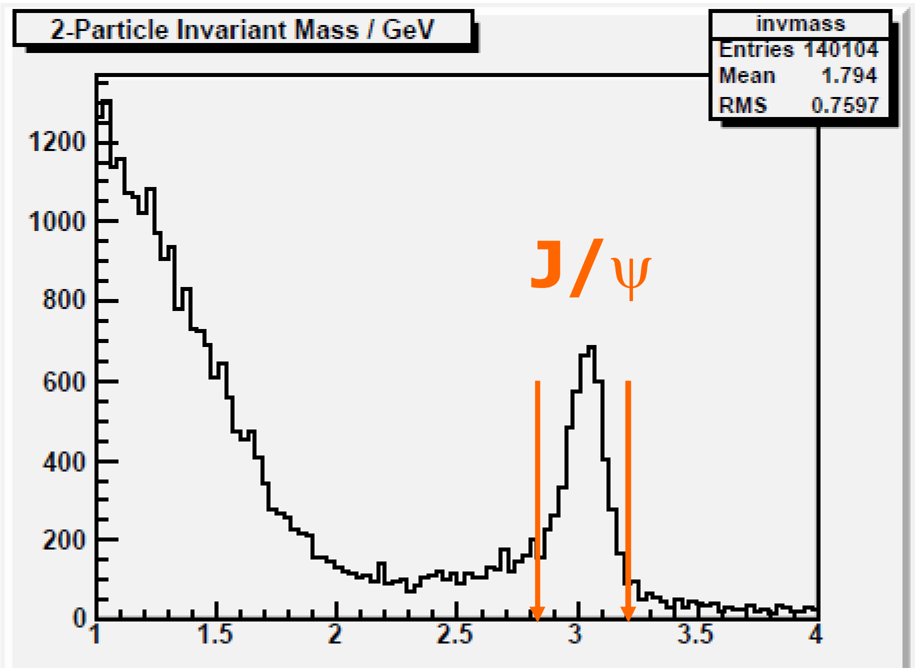
XYZ coordinates / cm

Beampipe Interaction

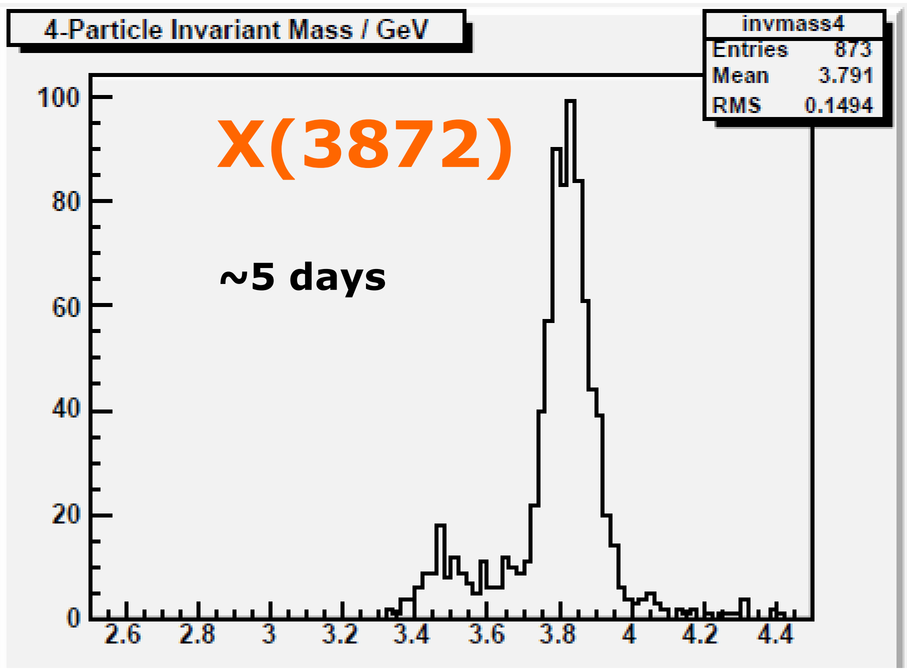
X(3872) at Panda, Invariant Mass Reconstruction

PandaRoot Simulation
$X(3872) \to J/\psi\ \pi^+\ \pi^-$
TPC digitization, MVD digitization
Conformal Map Track Finder

J/Psi Mass Cut 3σ
$|p_z| < 0.05$ GeV/c
(suppress $J/\psi \to e^+ e^- \gamma$)



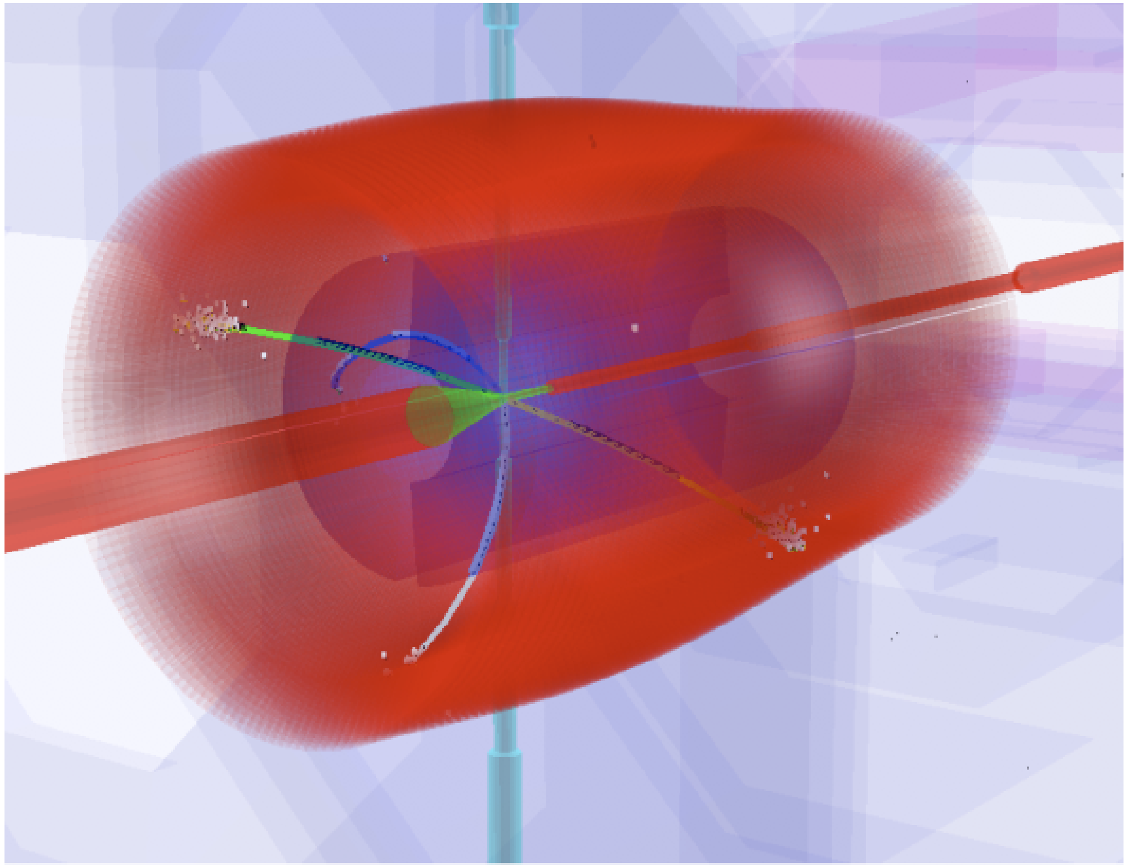
2-Particle Invariant Mass / GeV



4-Particle Invariant Mass / GeV

Expected Yield: $\sigma \cdot BR \simeq 250$ pb, N~200 events per day

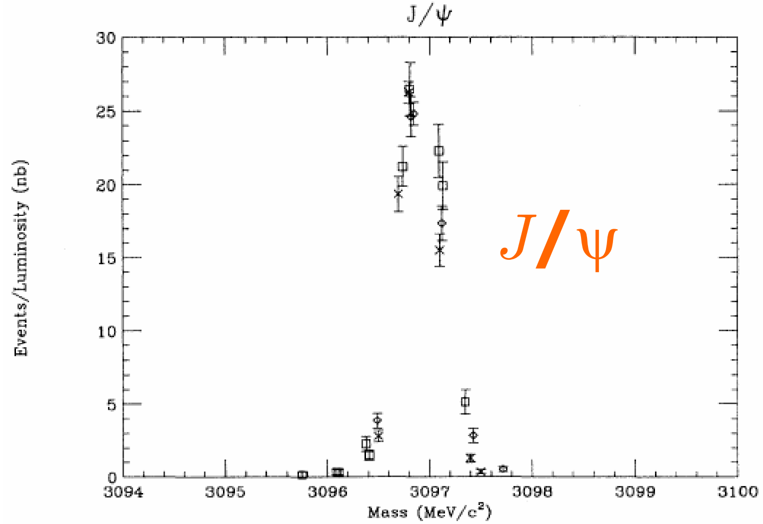
X(3872)→ J/ψ $\pi^+ \pi^-$ Event, Panda Simulation

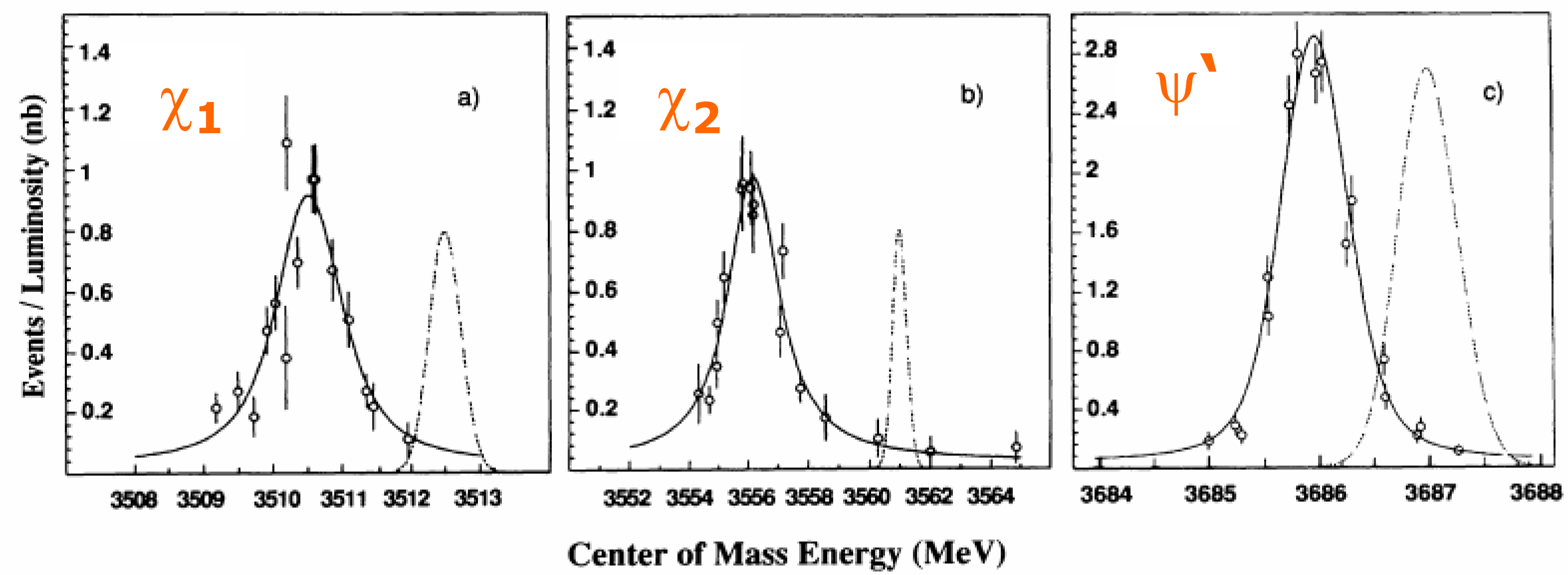


Main Background: $\bar{p}p \rightarrow \pi^+ \pi^- \pi^+ \pi^-$, σ~0.05 mb
both pions mis-identified and in J/ψ mass region, S/N~1/24

Panda will be able to measure the width of the X(3872)

- **using cooled $\bar{p}$-beam**
- **Example: Experiment E760, E835**
  Phys. Rev. D 47(1993)772
- **Width of J/ψ measured**
  Γ=99±12±6 keV
  using beam energy resolution
  $\Delta E_{beam} \simeq$0.5 MeV





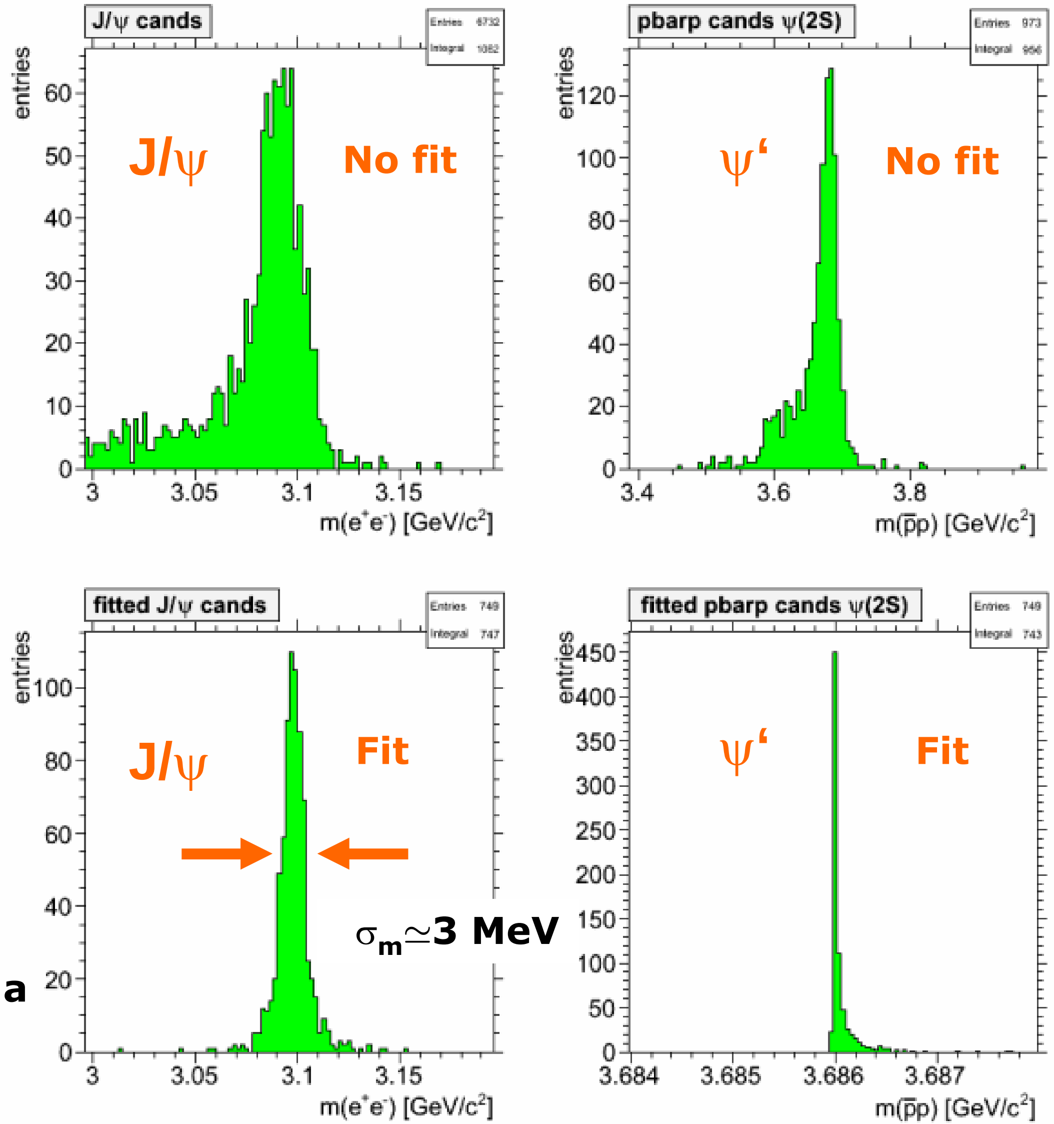
Kinematic Fit:
Vertex Constraint and Mass Constraint

Example:

reference mode

$\psi' \rightarrow J/\psi \; \pi^+ \pi^-$

↑ **Constraint**

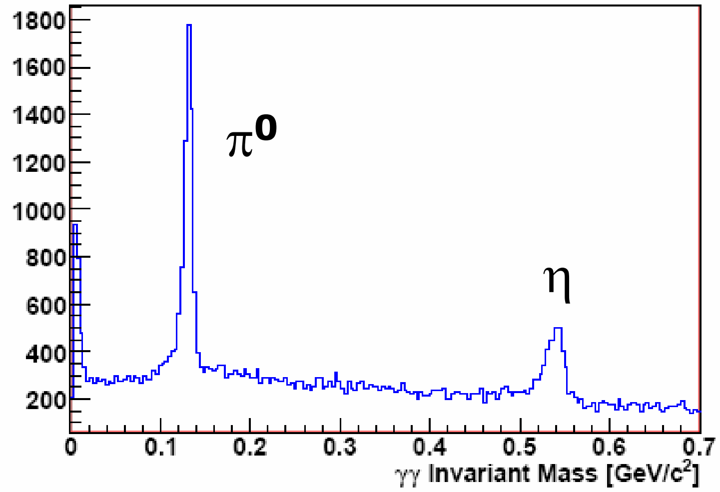


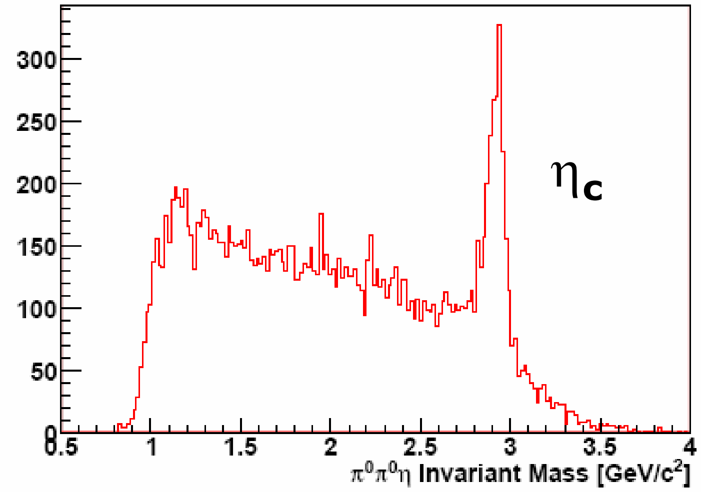
Current upper limit width of X(3872)
Γ < 2.3 MeV
(Belle, $J/\psi \; \pi^+\pi^-$ mode)

Preliminary estimate for Panda
$\Gamma \geq$168 keV for $\delta p/p=10^{-4}$

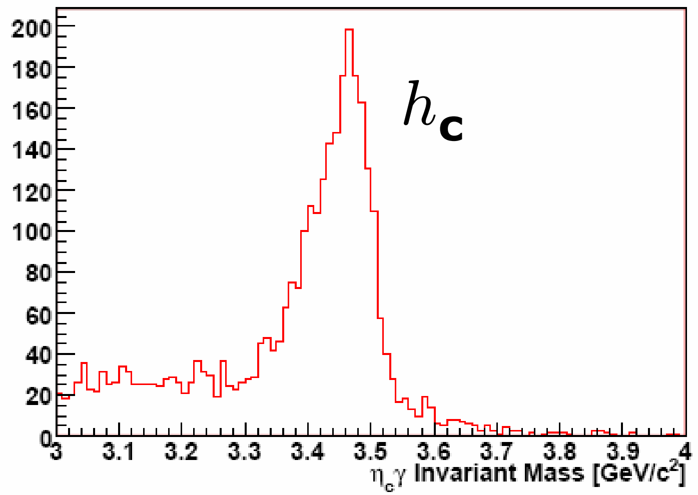
$h_c \rightarrow \eta_c\gamma \rightarrow \eta\pi^0\pi^0\gamma \rightarrow \gamma\gamma\gamma\gamma\gamma\gamma\gamma$

7 photon final state, σ = 16.8 ± 2.7*pb* (*E*835) x BR($\eta_c \rightarrow \eta\ \pi^0\ \pi^0$)





$\varepsilon \geq$ **40%**



7-particle invariant mass

→ see talk by Aleksandra Biegun, June 7, 16:50

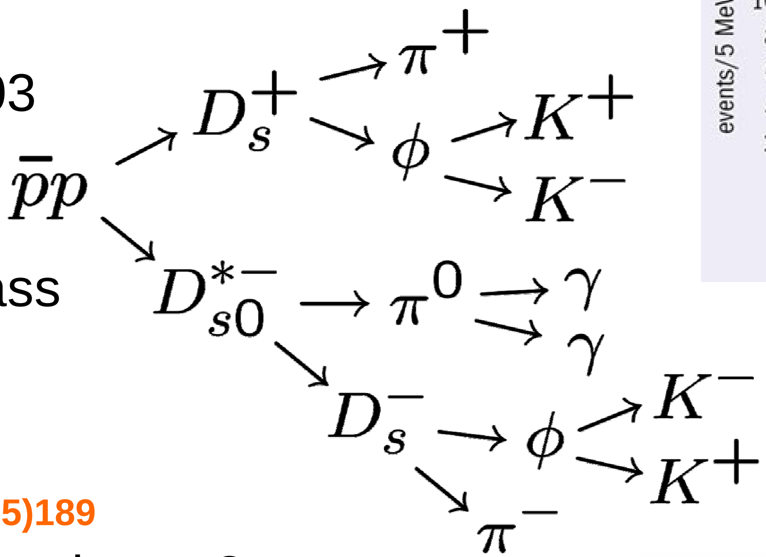
Note: w/o cuts 7!=5400 combinations

Panda Physics Example #2:

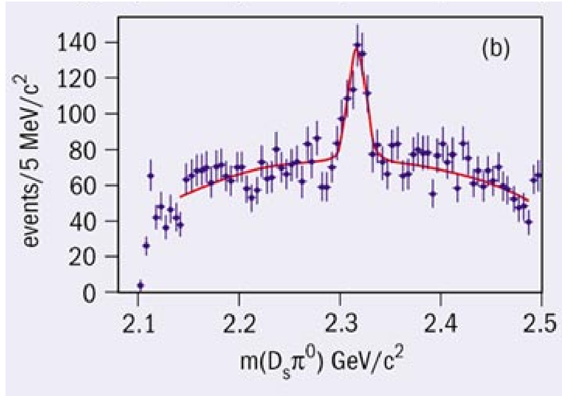
Charmed Mesons
D_{SJ}

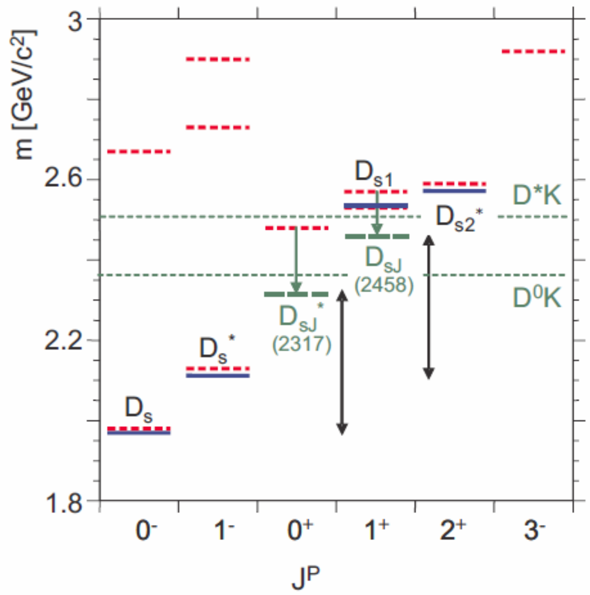
$D_{s0}(2317)$

- found by BaBar, 2003
- [c $\bar{s}$] L=1 meson
- Non-understood:
  ≃100 MeV lower mass than predicted from established potential models
  Godfrey, Isgur, PRD 32(1985)189
- Chiral partner to ground state?
  Nowak, Rho, Zahed
  Acta Phys. Polon. B35(2004)2377
- for Panda: production at threshold
  $\sqrt{s}$ = 4.306 GeV
  (p_{pbar} = 8.8931 GeV/c)
- 8 final states
- Reconstruction full exclusive
  (for background rejection)



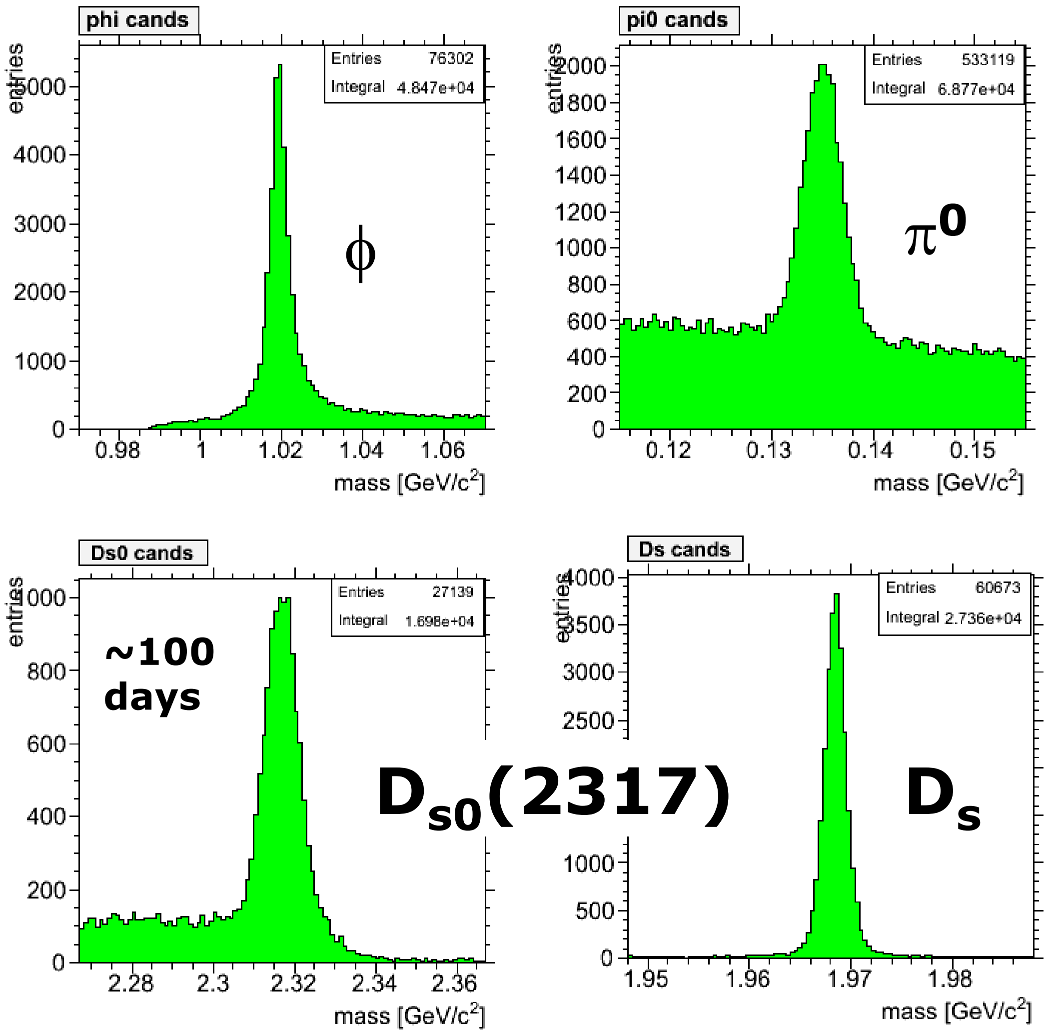
BaBar, Phys. Rev. Lett. 90(2003)242001





Fast Simulation

Detector Resolutions parametrized
1-1.5 kHz Simulation & Reconstruction Rate



Yield Estimate

Cross Section σ~1 nb
Integrated Luminosity per day: 8 pb^{-1}
BR($D_s \rightarrow \phi\,\pi$)=0.044
BR($\phi \rightarrow$ K+ K-)=0.49
Efficiency ~0.3

$\rightarrow$ ~60 events/day

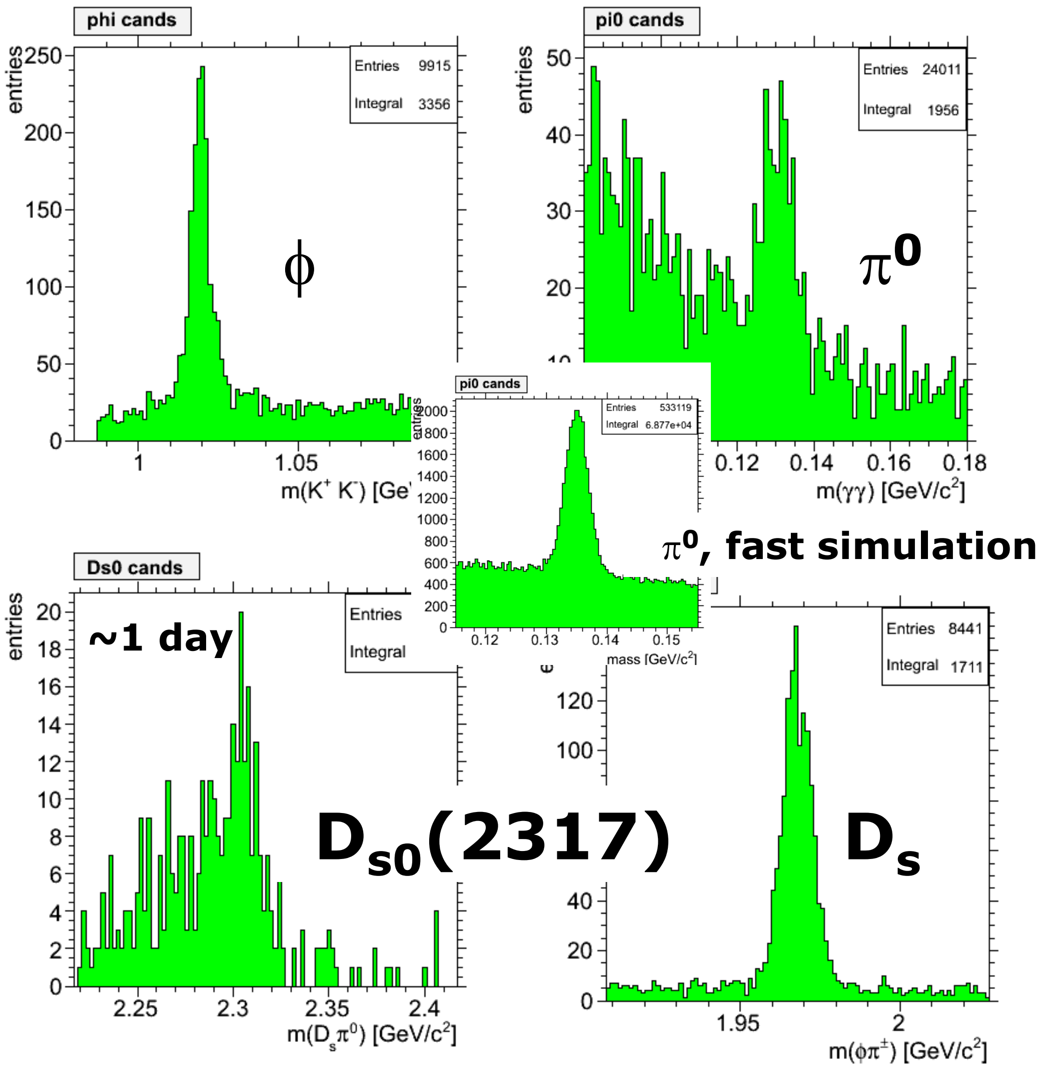
Background

- **non-resonant $\bar{D}_s\, D_s\, \pi^0$ S/N $\simeq$ 1/10**
- **dual parton model background negligible <10^{-6}**

Full Simulation

Geant3.15

$\leq$1 Hz Data Simulation & Reconstruction Rate

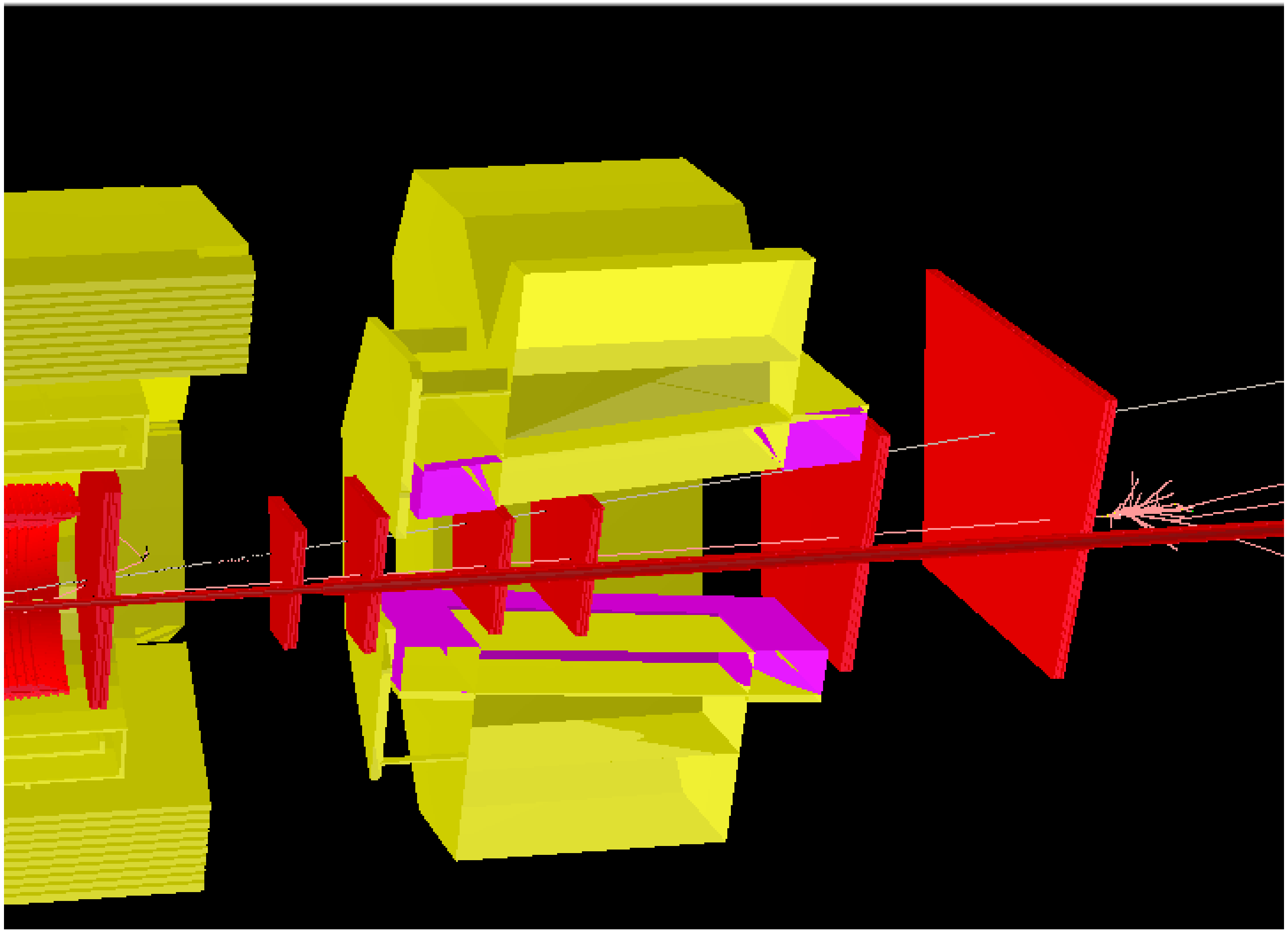


Measurement of D_{SJ} width:
Preliminary Panda estimate
$\Delta\Gamma \geq$ 192 keV for $\delta p/p=10^{-4}$
$\Delta\Gamma \geq$ 19 keV for $\delta p/p=10^{-5}$

Predictions:
Lutz, Soyeur,
arXiv:0710.1545[hep-ph]
$\Gamma \simeq$ 140 keV
Faessler, Gutsche,
Lyubovitskij, Ma
Phys. Rev. D76 (2007) 014005
$\Gamma \simeq$ 46.7 keV

for $\bar{p}p \rightarrow D^+ D^-$, $\bar{D}^0 D^0$

See Talk by Rene Jäkel, June 7, 17:10



Forward Spectrometer:
see Aleksandra Wronska's Talk, June 7, 17:30

Summary

- Panda will offer unique possibilities for QCD studies
  - Charmonium Spectroscopy
    - all quantum numbers in formation, C=+1 states
    - highly excited states (n=3,4,…,L=2,3,…)
      mass>4.75 GeV (not accessible at BES-III or Super-Belle)
    - measure the width using cooled antiprotons
  - Charmed Mesons D_{sJ}
  - Double Hypernuclei
  - Glueballs, light (u,d,s) Hybrids
  - (Unpolarized) Drell-Yan $\rightarrow$ Transverse Spin Physics
  - $p\ \bar{p} \rightarrow \gamma\ \gamma$, Generalized Parton Distributions
  - Charm in the Nuclear Medium
  - G_E, G_M Formfactors $\rightarrow$ see talk by Frank Maas, June 7, 09:00
  - And maybe more …

The PANDA Collaboration

More than 420 physicists from 55 institutions in 17 countries

U Basel
IHEP Beijing
U Bochum
U Bonn
U & INFN Brescia
U & INFN Catania
Cracow JU,TU, IFJ PAN
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati

U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
U Helsinki
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Mainz
U & Politecnico & INFN
Milano
U Minsk
Moscow, ITEP & MPEI
TU München
U Münster
BINP Novosibirsk
LAL Orsay

U Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U Oriente, Torino
U & INFN Trieste
U Tübingen
U & TSL Uppsala
U Valencia
SMI Vienna
SINS Warsaw
U Warsaw