3rd International Conference on New Frontiers in Physics

Search for Charmonium(-like) (Exotic) States at $\overline{\text{P}}$ANDA

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HIC for FAIR Helmholtz International Center

HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research

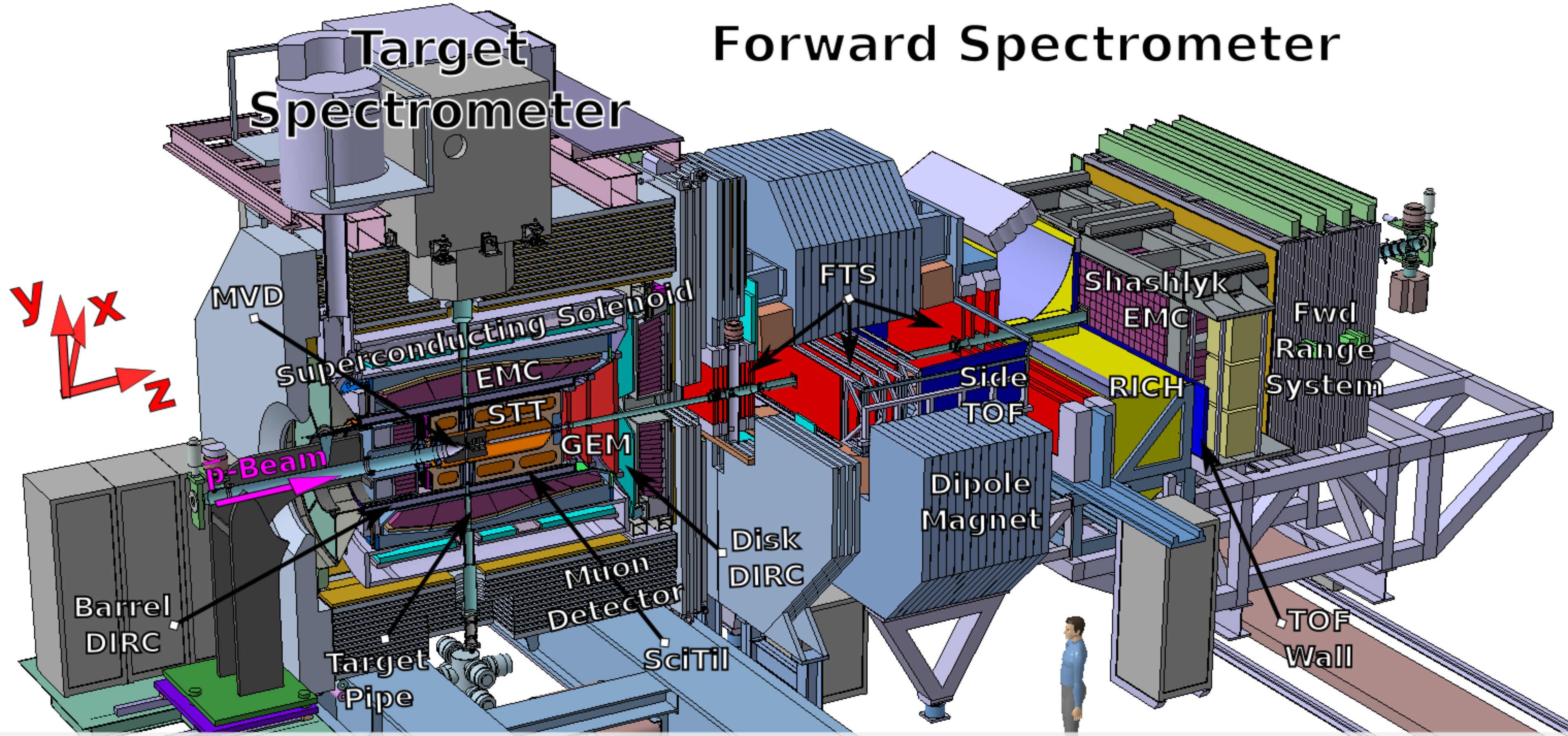
Bundesministerium für Bildung und Forschung

Outline

- The $\overline{\text{P}}$ANDA Experiment
- Simulations for Experimental Techniques
  - Resonance Scan
  - Radiative Cascade
  - Recoil Mass Technique
- Conclusions and Outlook

The $\overline{\text{P}}$ANDA Detector

For details see talk by G. Boca:
„The Experiment PANDA: Physics With Antiprotons at FAIR“,
July, 29th @ FAIR workshop



Detector Requirements

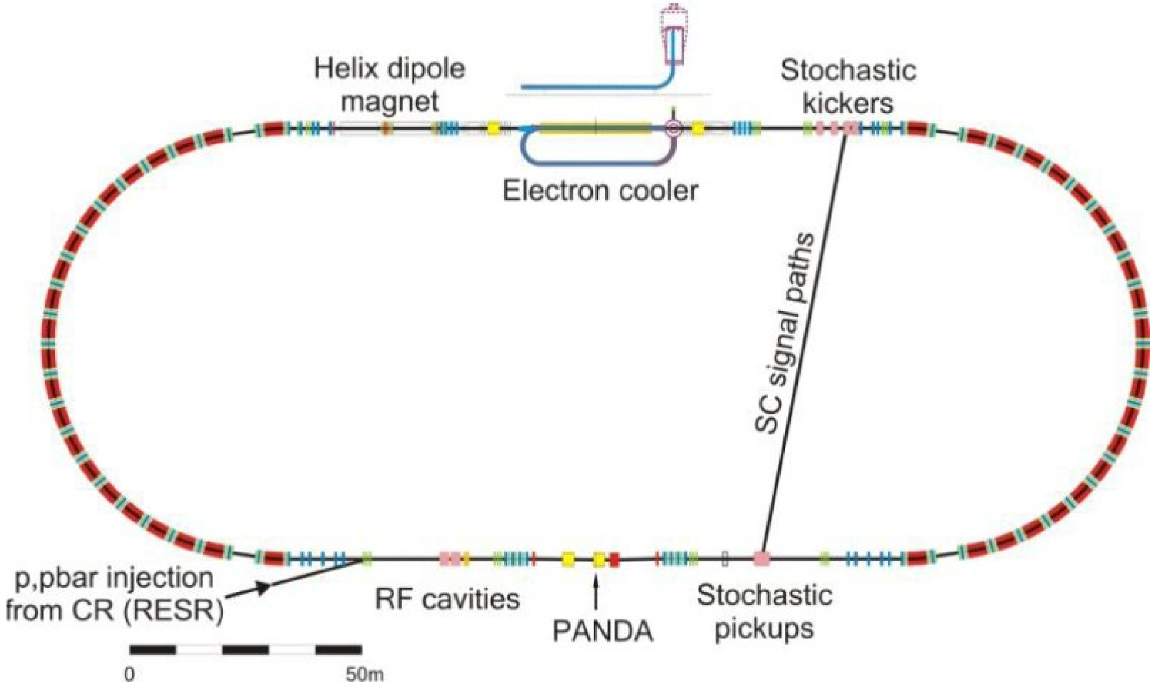
- $\approx 4\pi$ coverage for partial wave analysis
- Momentum resolution of $\approx 1\%$
- Vertexing for D, K^0_S, Λ
- Good PID for $\gamma, e^\pm, \mu^\pm, \pi^\pm, K, p$
- High rates of up to $2 \cdot 10^7$ annihilations/s
- High raw data rates in the order of 100 GB/s

The High Energy Storage Ring (HESR)

Operation Mode	**High Resolution Mode**	**High Luminosity Mode**
# stored antiprotons	10^{10}	10^{11}
Luminosity	Up to $2*10^{31}$ cm^{-2} s^{-1}	Up to $2*10^{32}$ cm^{-2} s^{-1}
$\Delta p_{beam}/p_{beam}$	$\leq 5*10^{-5}$	$1*10^{-4}$
Beam cooling	Electron cooling + Stochastic cooling	Stochastic cooling

Circumference	575 m
Momentum	1.5 – 15 GeV/c
Electron Cooling	up to 9 GeV/c
Stochastic Cooling	Full range
Beam life time	> 30 min.

For details see talk by D. Prasuhn:
„HESR@FAIR: The High-Energy Storage Ring“,
July, 28th @ FAIR workshop

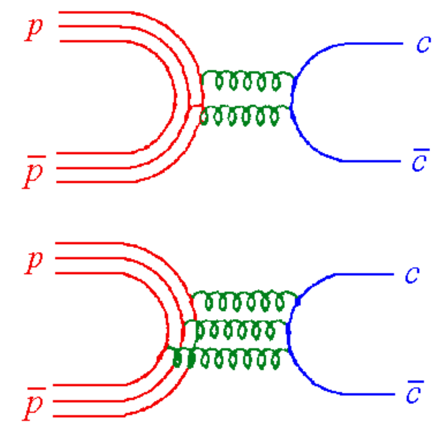


Charmonium(-like) States at $\overline{\text{P}}$ANDA

- High mass and high angular momentum states accessible
  $p_{beam} \leq 15$ GeV/c → $m_{c\bar{c}} \leq 5.5$ GeV for $\bar{p}p \to c\bar{c}$
  L ≥ 10 possible
- High statistics
  $\sigma_{\bar{p}p \to c\bar{c}} = 50$ nb → 4.3 x 10^5 events per 1 day (high luminosity mode)
- All quantum numbers accessible in production
- All non-exotic quantum numbers accessible in formation
  Resonance scans
- Excellent E_{cm} resolution
  FWHM = 160 keV @ $m_{c\bar{c}} = 4$ GeV (in high resolution mode)
- Gluon-rich environment
- High hadronic background

$c\bar{c}$ formation in $\bar{p}p$ annihilation

2 gluons:
$0^{-+}, 0^{++}, 2^{++}, \ldots$



3 gluons:
$1^{--}, 1^{+-}, \ldots$

Resonance Scan

Isolated resonance R of mass M_R, small total width Γ_R and spin J
Formation in collision of 2 particles (spin S_1, S_2, not γ)
k center of mass momentum in initial state i

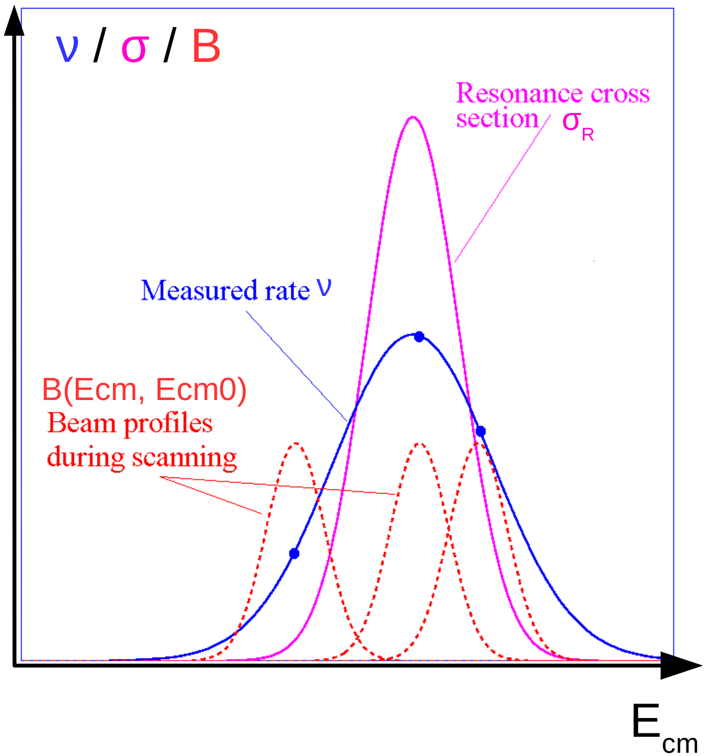
- For processes of the form
  Initial state → R → final state
  σ_R given by the Breit-Wigner formula:

$$\sigma_{\mathrm{BW}}(E_{\mathrm{cm}}) = \frac{(2J+1)}{(2S_1+1)\cdot(2S_2+1)} \cdot \frac{\pi}{k^2} \cdot \frac{\mathcal{B}_{\mathrm{in}}(i)\cdot\mathcal{B}_{\mathrm{out}}(f)\cdot\Gamma_R{}^2}{(E_{\mathrm{cm}}-M_R)^2+\Gamma_R{}^2/4}$$

- Count rate ν:

$$\nu = \mathcal{L}\cdot\left(\varepsilon_{\mathrm{sig.}}\cdot\int\sigma_{\mathrm{BW}}(E_{\mathrm{cm}})\cdot B(E_{\mathrm{cm}},E_{\mathrm{cm0}})\,dE_{\mathrm{cm}} + \varepsilon_{\mathrm{bkg.}}\cdot\sigma_{\mathrm{bkg.}}\right)$$

- $B(E_{cm},E_{cm0})$: Beam energy distribution around nominal value E_{cm0}
- Measure rate as function of the cm energy E_{cm0}.
  → M_R, Γ_R and $B_{in}*B_{out}$.
- Resolution only limited by knowledge of cm energy.
- PID and momentum resolution needed for background suppression.



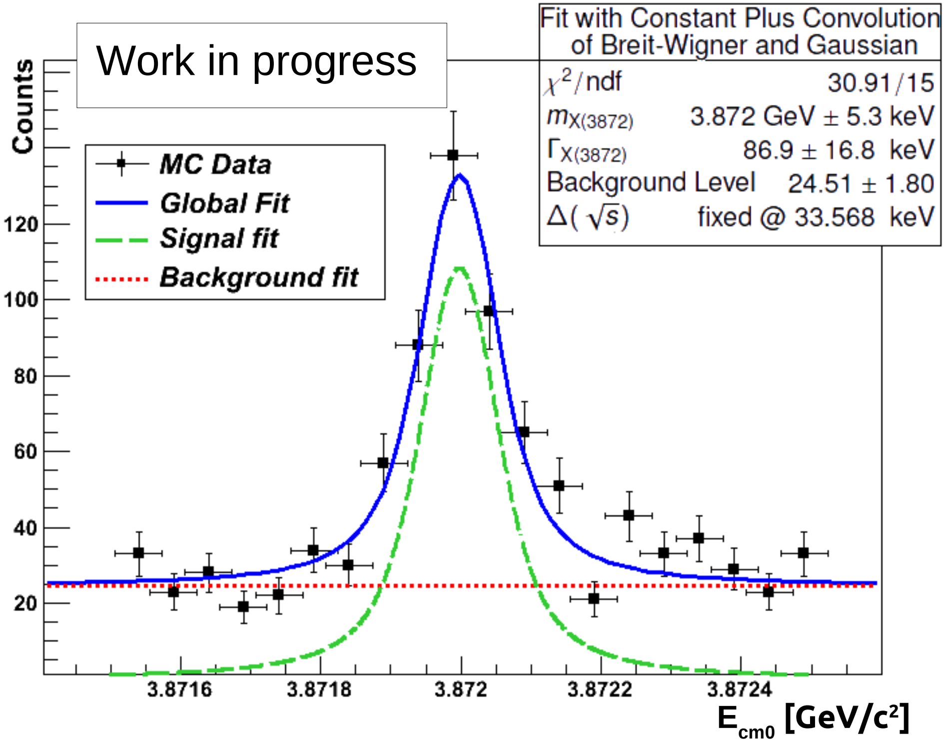
X(3872) Resonance Scan at $\overline{\text{P}}$ANDA

For an introduction to XYZ states see talk by W. Kühn: „BESIII Highlights“, July, 29th @ FAIR workshop

- X(3872) formation in e^+e^- annihilations suppressed due to $J^{PC}=1^{++}$
- Background Study for $E_{cm} = m_{X(3872)}$
  $\bar{p}p$ inelastic: $\sigma_{inel.} \approx 45$ mb
  $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-$: $\sigma_{4\pi} \approx 50$ μb
  $\bar{p}p \to J/\psi\, \pi^+\pi^-$: $\sigma_{direct} \approx 1.2$ nb

Study with Dual Parton Model (DPM) generator
Background Rejection $O(10^6)$ achieved

Included in plot



More details can be found in PoS(Bormio2012)018.
Simulation assumptions are consistent with new data.

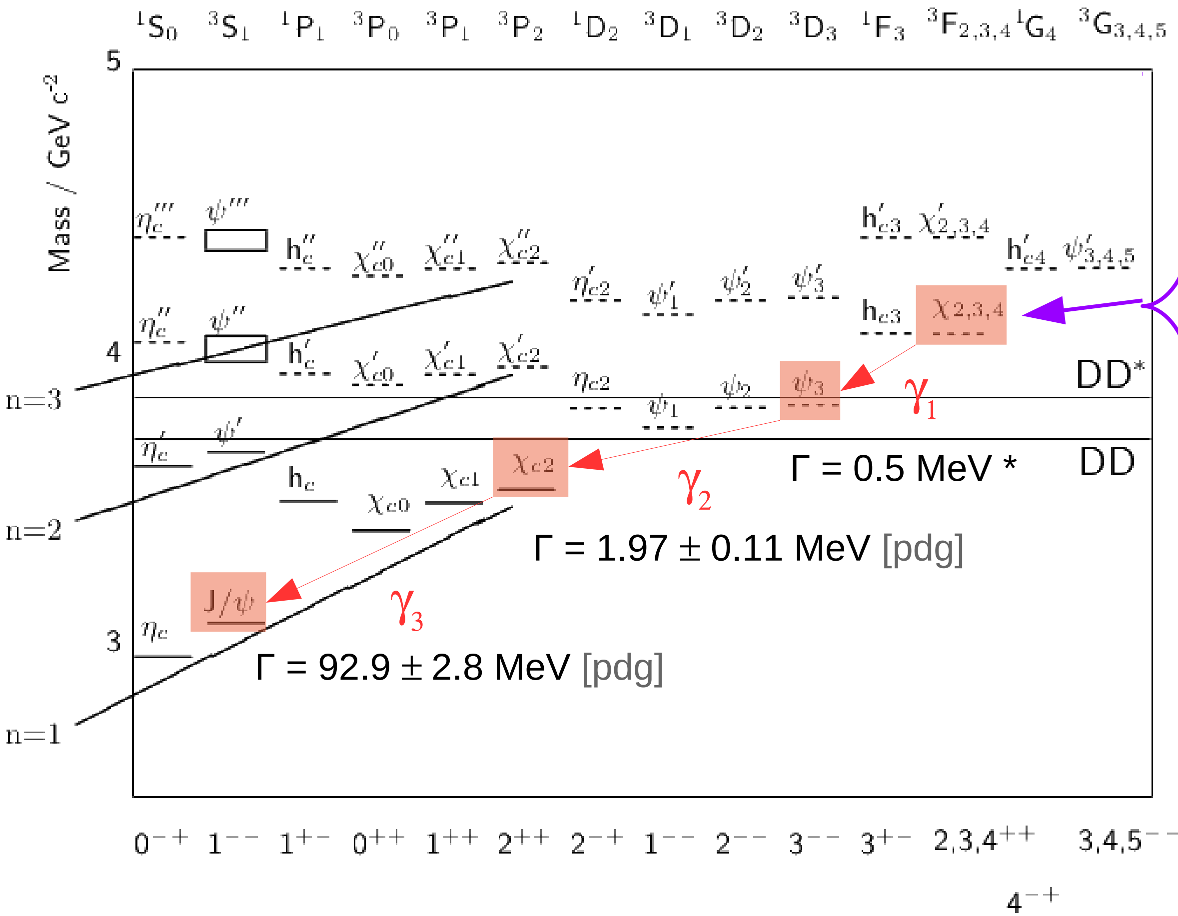
Formation	$\bar{p}p \to X(3872)$ (σ_{BW}=50 nb)
Reconstruction via	$J/\psi\ (\to e^+ e^-)\ \pi^+ \pi^-$ (BR = 0.1 * 0.06 [pdg])
HESR	High resolution mode
Req. Time	20 * 2 days
Acc. Duty Factor	50%

- $\overline{\text{P}}$ANDA will be able to either measure $\Gamma_{X(3872)}$ or at least significantly improve the current upper limit of $\Gamma_{X(3872)} < 1.2$ MeV at 90% C.L.*

* S.-K. Choi et al. (Belle Collaboration) Phys. Rev. D 84, 052004 (2011).

Radiative Cascade for $^3F_4$ (= $^{2S+1}L_J$) $c\bar{c}$ state

- Formation of high angular momentum resonance $^3F_4$.
- Decay to ground state and to open charm suppressed by angular momentum barrier.
- Decay via a γ cascade (ΔL=1) with narrow intermediate resonances can be used to identify the resonance.



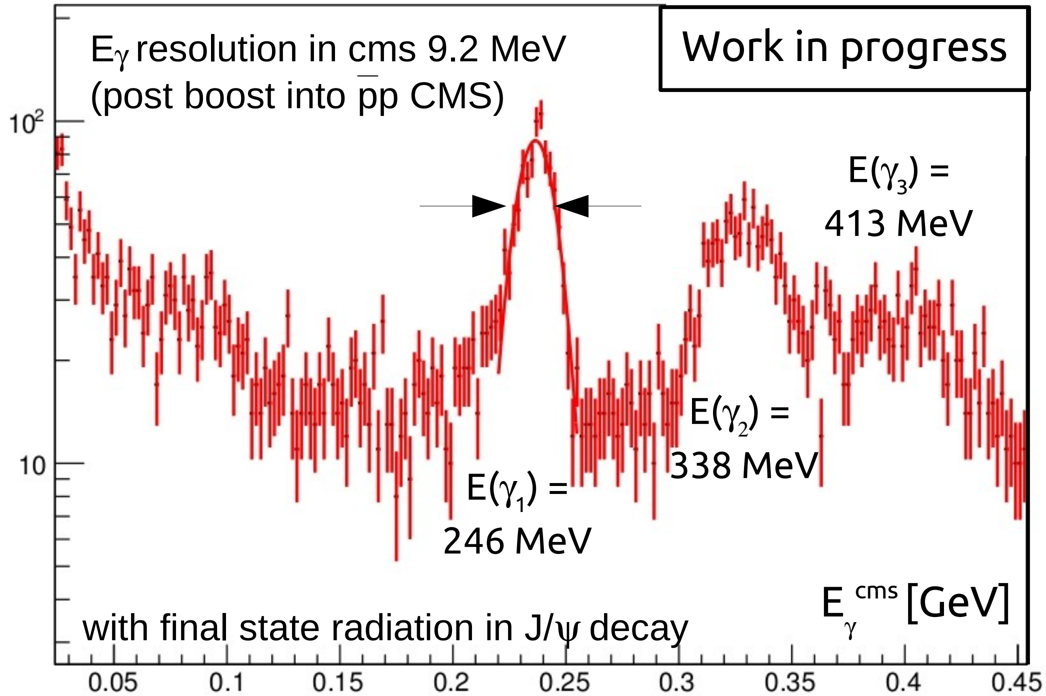
Predicted mass
m = 4021 – 4095 MeV/c² *

Predicted width
Γ = 8.3 MeV *

$J^{PC}=4^{++}$, *n=1*, *S=1*, *L=3*
→ Cannot be formed in e^+e^- annihilations
→ Suppressed in *B* decays
→ Suppressed in radiative ψ decays
→ Formation in $p\bar{p}$ not suppressed

* Mass and width predictions by Barnes, Godfrey, Swanson Phys. Rev. D72(2005)054026

Search for $^3F_4$ at $\overline{P}$ANDA



Production	$\bar{p}p \to {}^3F_4$ (σ=10 nb)
Reconstruction via	${}^3F_4 \to {}^3D_3\ \gamma_1$ (BR=0.1) ${}^3D_3 \to \chi_{c2}\ \gamma_2$ (BR=0.1) $\chi_{c2} \to J/\psi\ \gamma_3$ (BR=0.1) $J/\psi \to e^+ e^-$ (BR=0.06) $J/\psi \to \mu^+ \mu^-$ (BR=0.06)
HESR	High luminosity mode
Time Req.	2 weeks
Acc. Duty Factor	50%

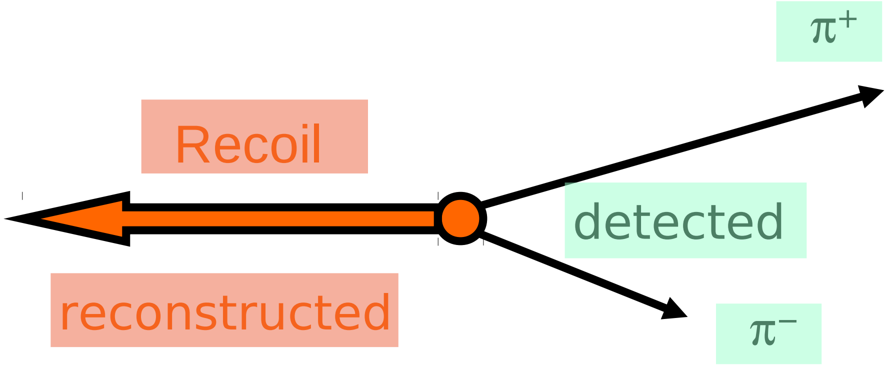
More details can be found in arXiv:1311.7597 [hep-ex].

- Branching fractions for radiative decays:
  $\psi' \to \chi_{c0}\gamma$ $\mathcal{B} = 9.84 \pm 0.31\%$ [pdg]
  → **Assume $\mathcal{B}$ = 10% for all 3 γ transitions.**

- Clean signature of **J/ψ + 3 γ with 150 MeV < E_{CMS} < 450 MeV.**
- 4C Fit with cut on χ^2 and on invariant mass to suppress background.

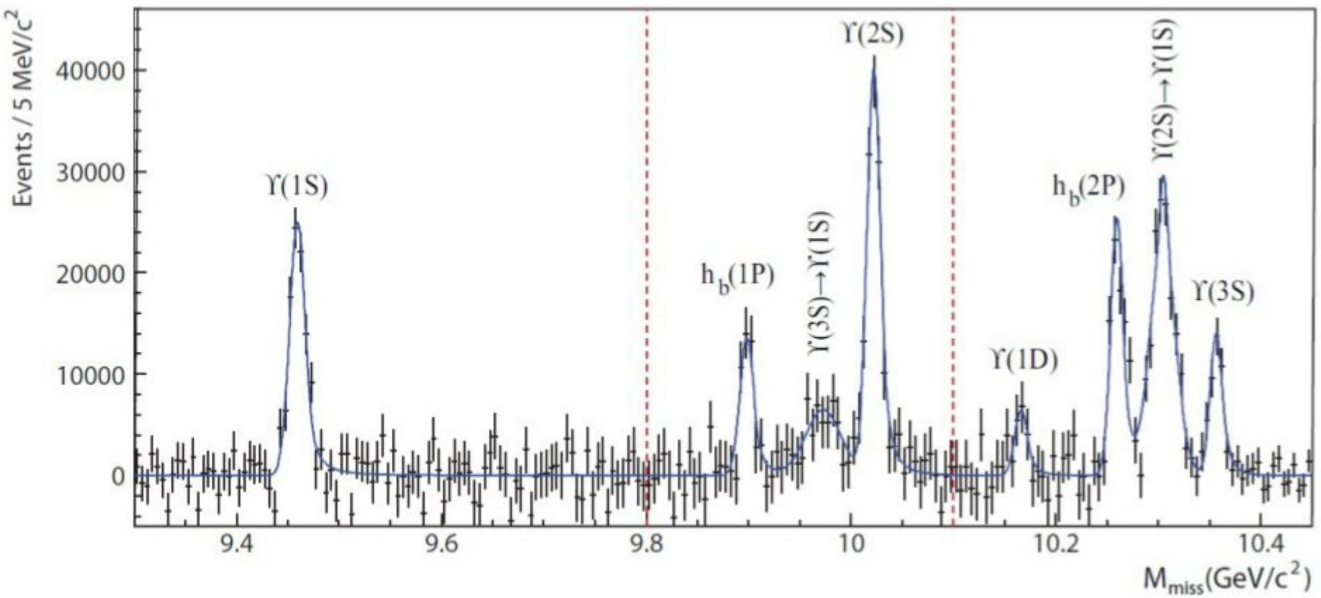
- Background simulation based on dual parton model [dpm] → γ from light hadron decays.

Recoil („Missing“) Mass Technique



$$M_{\mathrm{miss}}(X) = \sqrt{(E_{\mathrm{c.m.}} - E_X^*)^2 - p_X^{*2}}$$

- Select events, reject background.
- Fit and subtract background from data.
- Fit background subtracted data → signal(s).



Method was used for finding h_b and h_b' at Belle

Belle, 121.4 fb^{-1}
Phys. Rev. Lett
108(2011)032001

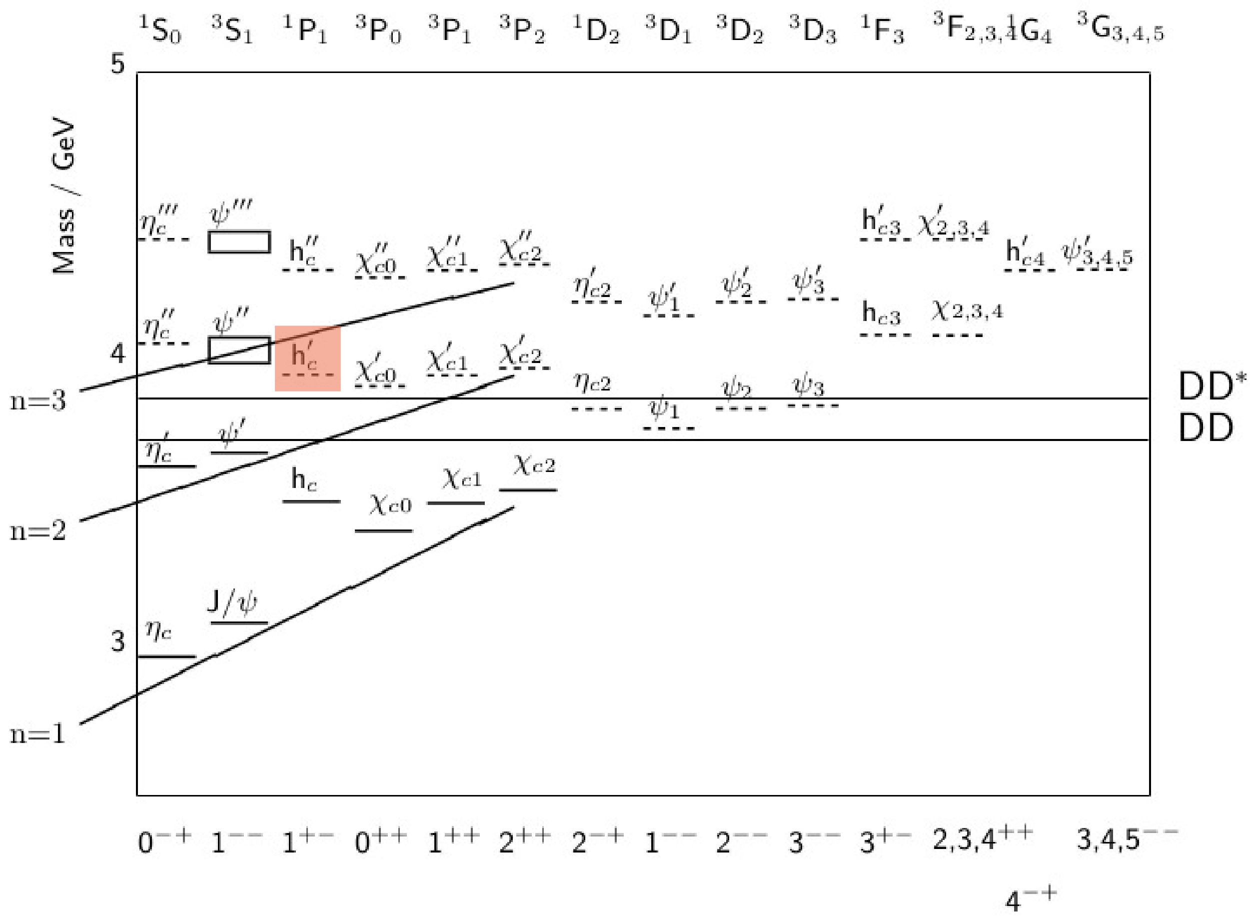
h_c' (n=2, $^{2S+1}L_J={}^1P_1$, $J^{PC}=1^{+-}$, $c\bar{c}$ state)

Prediction from potential model
m = 3934 – 3956 MeV/c² *

Predicted width Γ=87 MeV/c²
(decay to $D\bar{D}$* open)

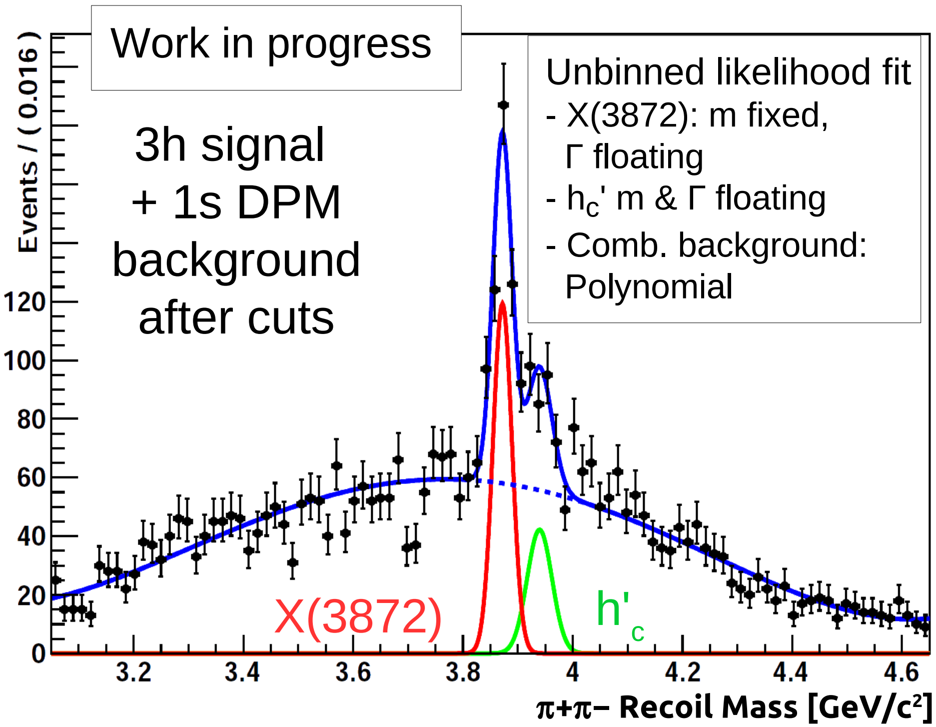
h_c' and h_c suppressed at B-Factories:
$0^{-+} \rightarrow 0^{-+} 1^{+-}$ (B → K h_c')
forbidden in factorisation limit.
(Additional gluon required between K and h_c')

h_c' and h_c suppressed at BESIII:
In 1^{--} decays,
1^{+-} can only be produced by
$1^{--} \rightarrow 1^{+-} \pi^0$
(isospin-violating → BR ≤ 10^{-3})



* Mass & width prediction by Barnes, Godfrey, Swanson
Phys. Rev. D72(2005)054026

h_c' Recoil Mass Search at $\overline{\text{P}}$ANDA



Process @ p_{beam} = 15 GeV/c	$\bar{p}p \to h_c'(\to D^0 \bar{D}^{0*})\ \pi^+ \pi^-$ (+ c.c.)
Subsequent Decays	$D^0 \to K^- \pi^+$ (BR=3.88%) [pdg] $\bar{D}^{0*} \to$ anything
HESR	High luminosity mode
Time Requirements	10 weeks
Acc. Duty Factor	50%
Signal Efficiency	8 %
Bkg. Suppression	$O(10^5)$

More details can be found in arXiv:1311.7597 [hep-ex].

Fit results	Input	Reconstructed
$m(h_c')$ [MeV/c²]	3945	3940±5
$\Gamma(h_c')$ [MeV]	87	54.2±40.0
$m_{X(3872)}$ [MeV/c²]	3872	Fixed
$\Gamma_{X(3872)}$ [MeV]	1.2	40.7±4.5 (detector resolution)

A signal cross section of σ ≈ 30 nb for
$\bar{p}p \to h_c'(\to D^0 \bar{D}^{0*})\ \pi^+ \pi^-$ (+ c.c.)
is required to achieve
$S/\sqrt{(S+B)} \geq 5$ in 10 weeks of data taking.

Conclusions and Outlook

- Simulations were shown for
  - X(3872) resonance scan
  - Radiative cascade for high angular momentum $c\bar{c}$ state $^3F_4$
  - Recoil mass technique for h_c'

- $\overline{\text{P}}$ANDA offers a multitude of ways to study charmonium(-like) resonances with $\bar{p}p$ annihilations for resonances with $m_{c\bar{c}} \leq 5.5$ GeV/c^2.
  - Unprecedented antiproton beam momentum resolution.

- $\overline{\text{P}}$ANDA is well suited for
  - scans of (narrow) resonances with any non-exotic quantum numbers.
  - search for resonances via the recoil method.
  - search for high angular momentum states.
  - search for glueballs and hybrids. (Not shown in this talk).

Thank you.

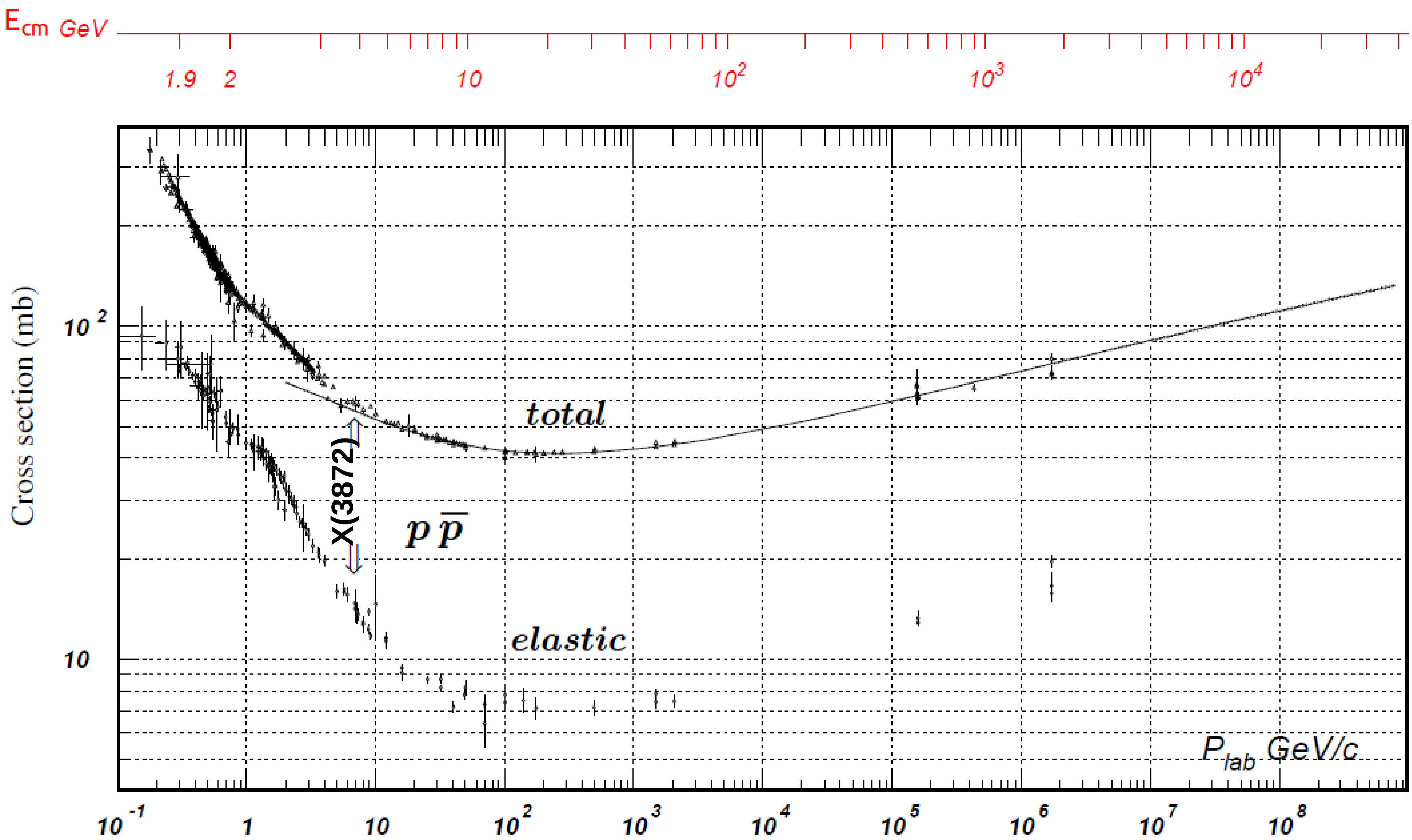
References

[pdg] J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012) and 2013 partial update for the 2014 edition.

[dpm] Dual Parton Model:
- A. Capella, U. Sukhatme, C.-I. Tan, J. Tran Thanh Van
  Phys. Rept. 236, 225 (1994)
- A. B. Kaidalov, P. E. Volkovitsky
  Z. Phys. C63, 517 (1994)
- V. V. Uzhinsky and A. S. Galoyan,
  hep-ph/0212369

BACKUP

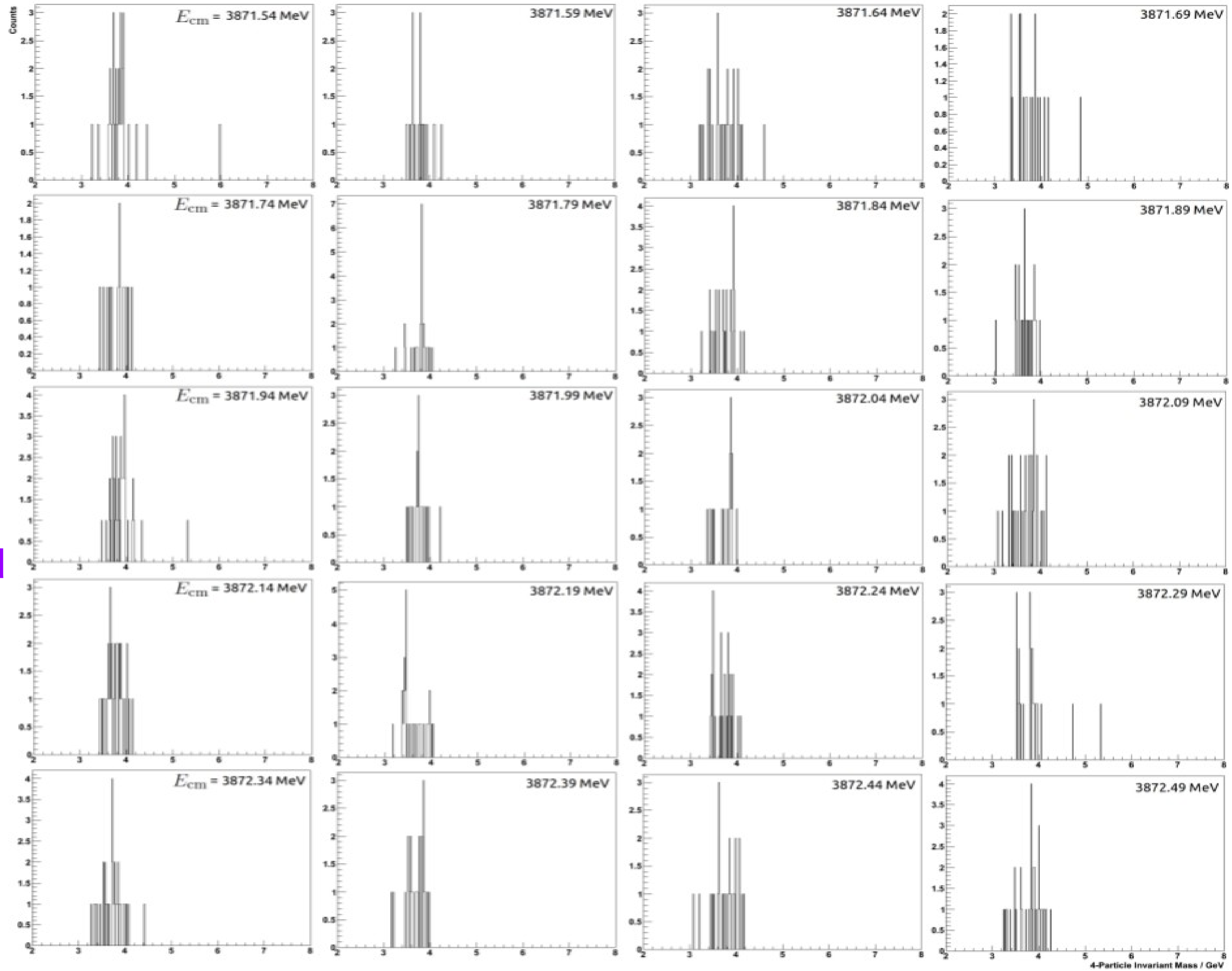
Background Cross Sections for $\bar{p}p$



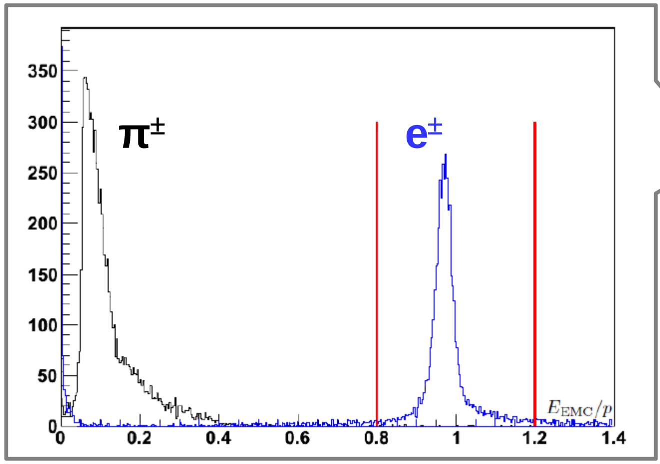
[pdg]

X(3872) Resonance Scan

Signal
σ_{sig} = 50 nb
+
Background from
$\bar{p}p \rightarrow J/\psi\, \pi^+\pi^-$
$\sigma_{bkg} \approx 1.2$ nb

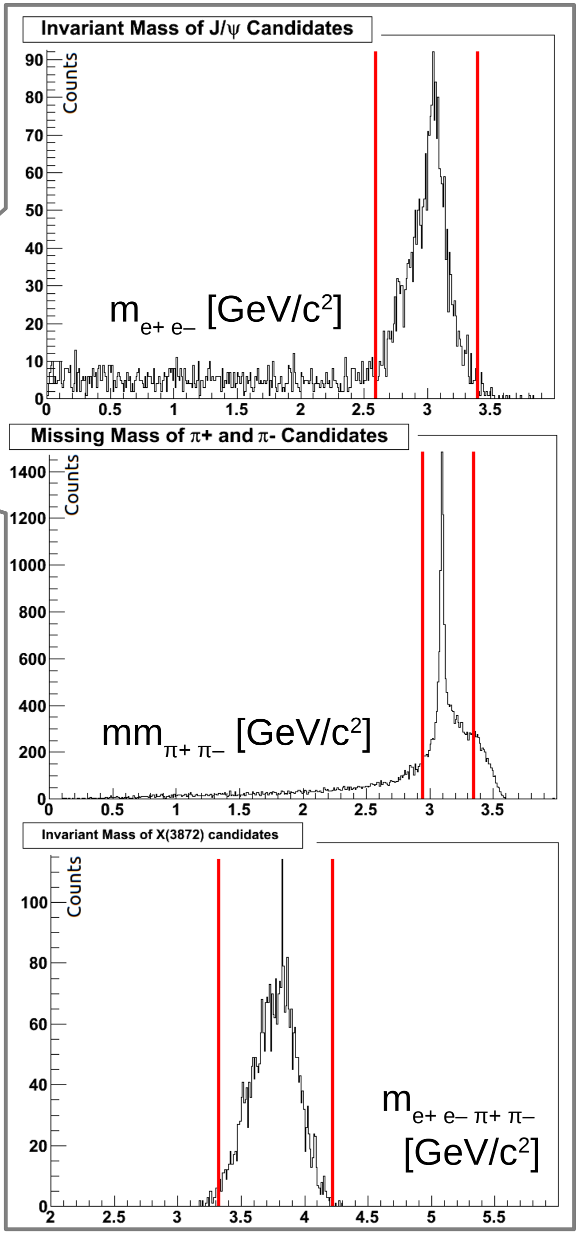


Background Rejection $O(10^6)$ for X(3872) Resonance Scan

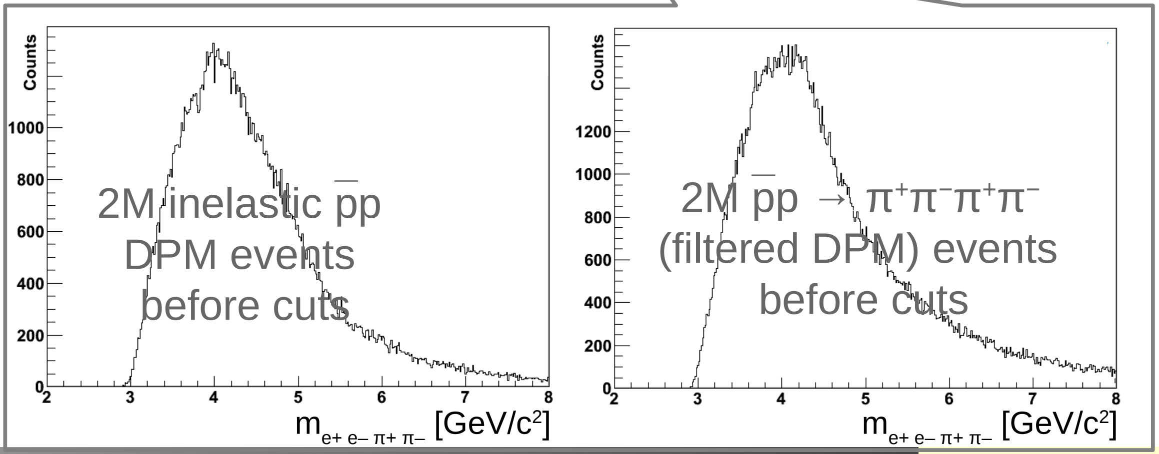


Event Selection for each scan point

- PID
  E_{EMC}/p for $e^{\pm}$ / $\pi^{\pm}$ discrimination
- ≥ 1 J/Ψ cand. via
  cut on $m_{e+\,e-}$
  cut on $mm_{\pi+\,\pi-}$
- ≥ 1 X(3872) cand. via
  cut on $m_{e+\,e-\,\pi+\,\pi-}$



After event selection cuts from 2M inelastic $\bar{p}p$ DPM events and 2M $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-$ (filtered DPM) events $O(1)$ remained in the signal region.



X(3872) → $\bar{p}$p Data From LHCb

In the Paper [lhcb13] “Measurements of the Branching Fractions of $B^+ \to p\bar{p}K^+$ Decays”. . .

- . . . the LHCb Collaboration studied

$$\frac{\mathcal{B}(B^+ \to \text{“mode”} K^+ \to p\bar{p}K^+)}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)}$$

  for several charmonium(-like) states “mode”
- One of these states is the X(3872)

LHCb Data Sample for Decay Channel $B^+ \to p\bar{p}K^+$

- Collected at $\sqrt{s} = 7$ TeV with p + p collisions
- $\mathcal{L}_{\text{int}} = 1.0\ \text{fb}^{-1}$ data
- $6951 \pm 176\ B^+ \to p\bar{p}K^+$ (+c.c.) decays reconstructed

[lhcb13] R. Aaij et al. (LHCb Collaboration): “Measurements of the Branching Fractions of $B^+ \to p\bar{p}K^+$ Decays”, LHCb-PAPER-2012-047, CERN-PH-EP-2013-040, arXiv:1303.7133 [hep-ex], submitted to EPJ C (2013)

Material from M. Galuska, Talk at PANDA CM June 2013

$X(3872) \to \bar{p}p$ Data From LHCb

The Result for X(3872) from the LHCb Paper [lhcb13]

- LHCb did not see any signal for the X(3872) and obtained an upper limit for

$$\mathcal{B}(B^+ \to X(3872)K^+ \to p\bar{p}K^+) < (1.7 \pm 0.1) \cdot 10^{-8} \quad (95\% \text{ C.L.})$$

which corresponds to

$$\frac{\mathcal{B}(X(3872) \to p\bar{p})}{\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)} < (2.0 \pm 0.2) \cdot 10^{-3} \quad (95\% \text{ C.L.})$$

Material from M. Galuska, Talk at PANDA CM June 2013

X(3872) → $\bar{p}p$ Data From LHCb

Upper Limit for X(3872) Peak Production Cross Section in $p\bar{p}$

The published upper limit [lhcb13]

$$\mathcal{B}(X(3872) \to p\bar{p}) < 2.0 \cdot 10^{-3} \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) \quad (95\%\ \mathrm{C.L.})$$

implies

$$\sigma^{\mathrm{peak}}_{[p\bar{p}\to X(3872)]} = \frac{(2 \cdot J + 1) \cdot 4\pi}{m_{X(3872)}{}^2 - 4m_p^2} \cdot \frac{\overbrace{\mathcal{B}(X(3872) \to p\bar{p})}^{<2.0\cdot 10^{-3}\cdot\mathcal{B}(X(3872)\to J/\psi\pi^+\pi^-)} \cdot \overbrace{\mathcal{B}(X(3872) \to \mathrm{all})}^{=1} \cdot \Gamma_{X(3872)}{}^2}{\underbrace{4(m_{X(3872)} - m_{X(3872)})^2}_{=0} + \Gamma_{X(3872)}{}^2}$$

$$\overset{(J=1)}{<} \frac{3 \cdot 4\pi}{m_{X(3872)}{}^2 - 4m_p^2} \cdot 2.0 \cdot 10^{-3} \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)$$

which depends on

$$\mathcal{B}(X(3872) \to J/\psi\,\pi^+\pi^-) > 2.6 \cdot 10^{-2}$$

for which only a lower limit is published [pdg12]

Material from M. Galuska, Talk at PANDA CM June 2013

X(3872) → $\bar{p}$p Data From LHCb

Tightest Upper Limit for X(3872) Peak Production Cross Section in p$\bar{p}$

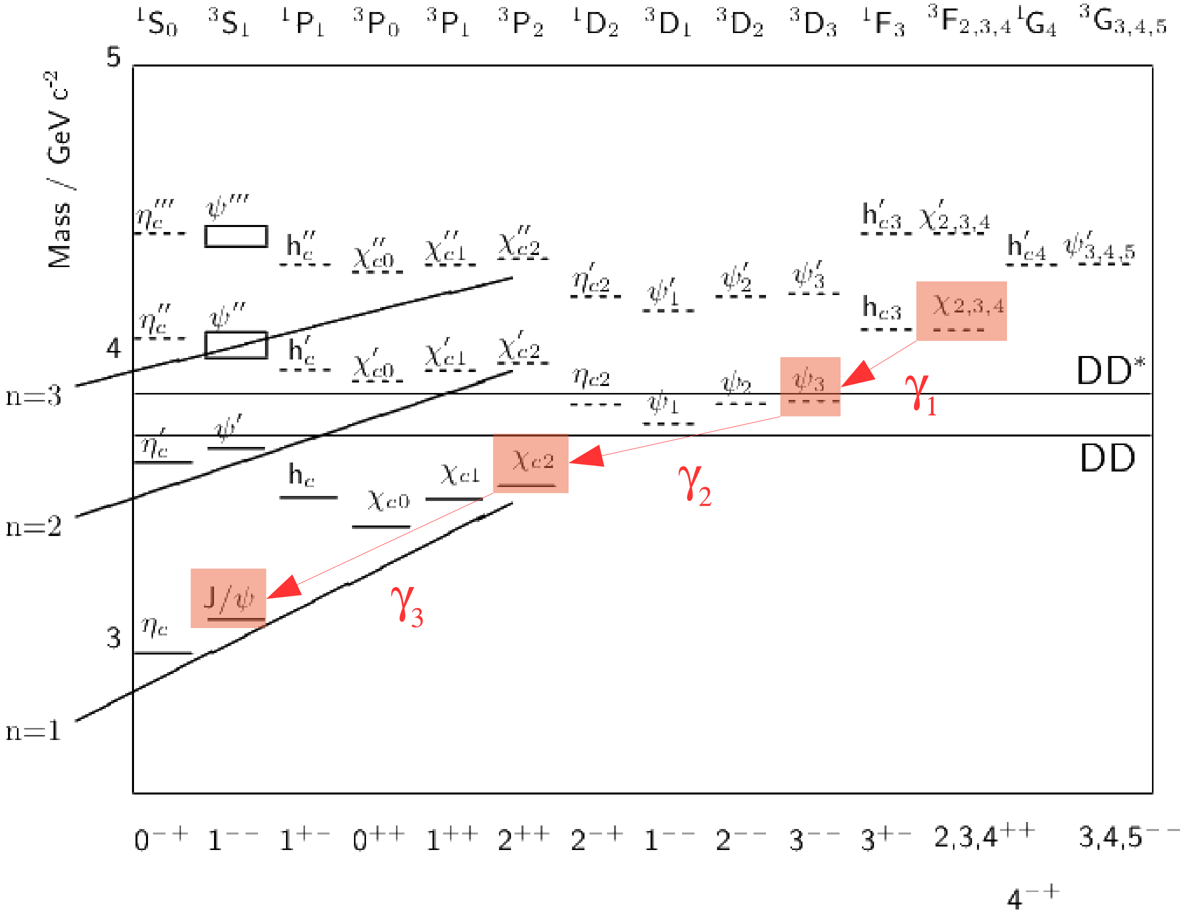
$$\sigma^{\text{peak}}_{[p\bar{p}\to X(3872)]} \overset{(J=1)}{<} \frac{3\cdot 4\pi}{m_{X(3872)}{}^2 - 4m_p^2} \cdot 2.0\cdot 10^{-3}\cdot 2.6\cdot 10^{-2} = 66.6 \pm 6.7\ \text{nb}$$

using $\mathcal{B}(B^+ \to X(3872)K^+ \to p\bar{p}K^+)$ the result is $68.0 \pm 4.0\ \text{nb}$

Material from M. Galuska, Talk at PANDA CM June 2013

Radiative Cascade for $^3F_4$ (= $^{2S+1}L_J$) $c\bar{c}$ state

Mass and width predictions by
Barnes, Godfrey, Swanson
Phys. Rev. D72(2005)054026



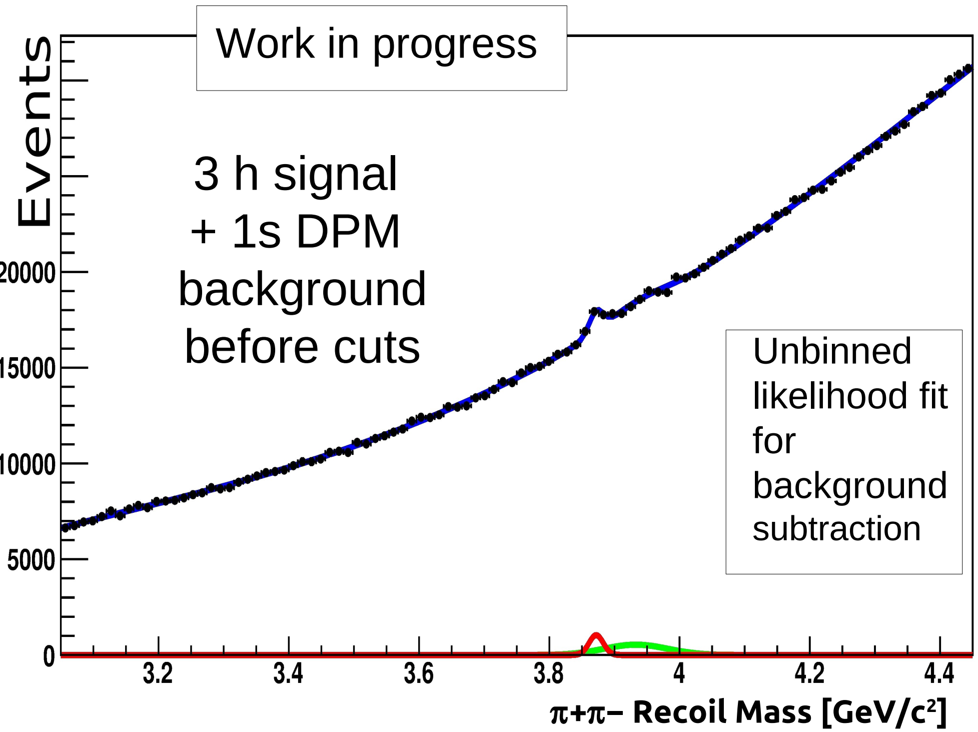
$1\ ^3F_4$
$J^{PC}=4^{++}$
4095 MeV
$\Gamma=8.3$ MeV
$E_\gamma=246$ MeV

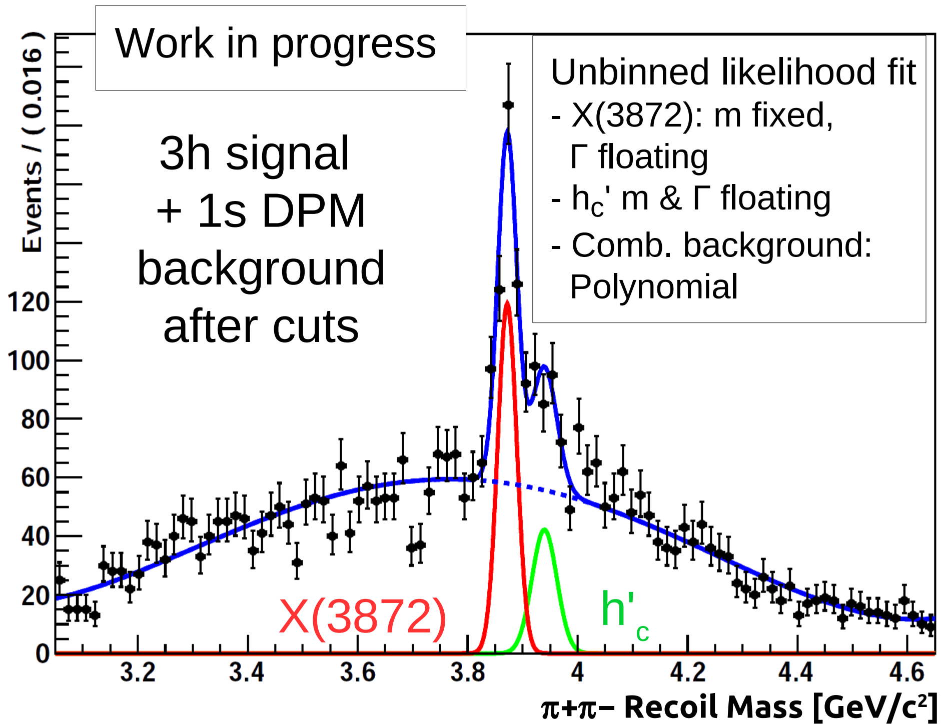
$1\ ^3D_3$
$J^{PC}=3^{--}$
3849 MeV
$\Gamma=0.5$ MeV
$E_\gamma=338$ MeV

χ_{c2}
$J^{PC}=2^{++}$
3556 MeV
$\Gamma=1.97$ MeV
$E_\gamma=413$ MeV

J/ψ
$J^{PC}=1^{--}$

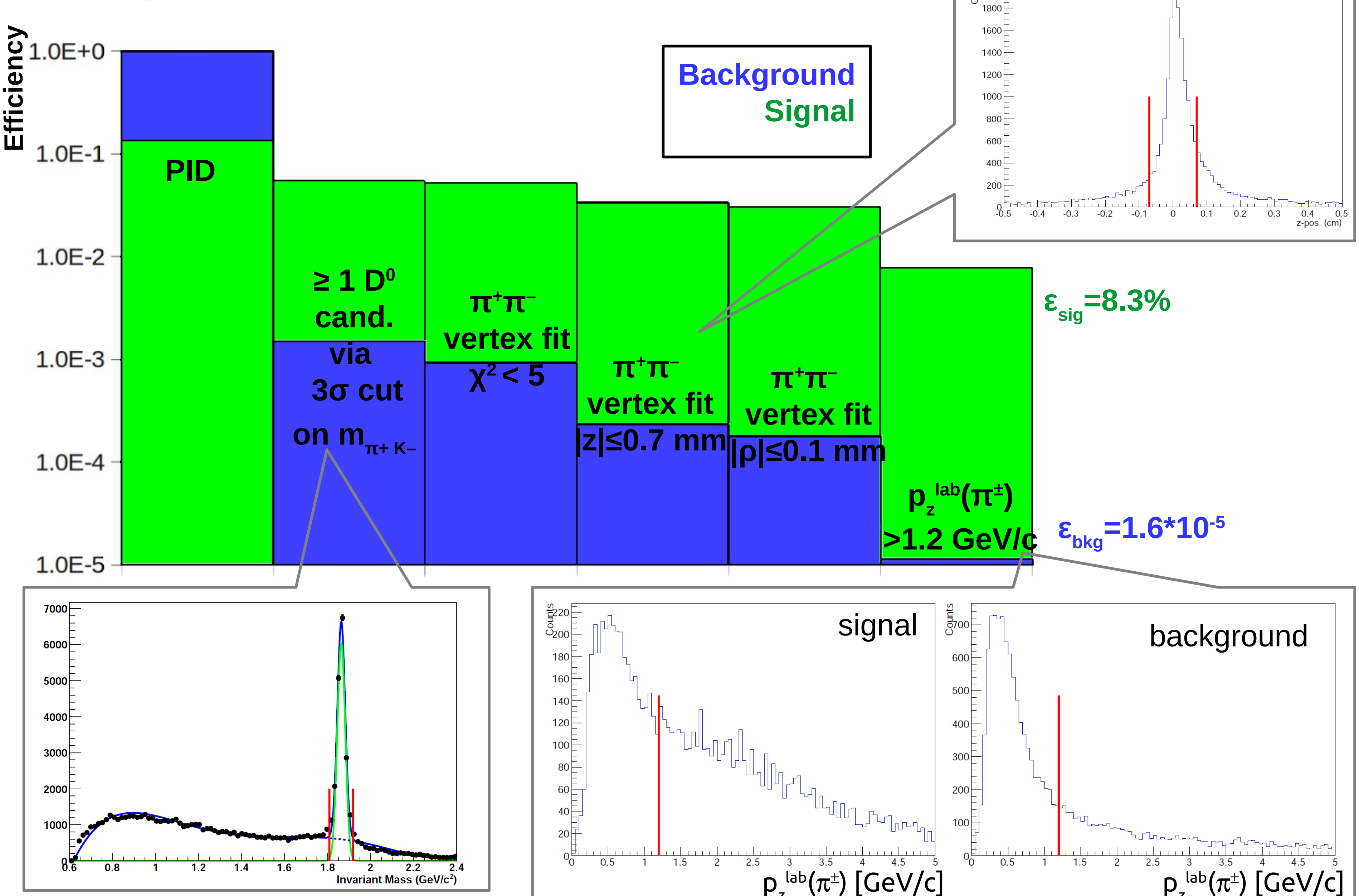
Background Subtraction for h_c' *Recoil Mass* Study





Applied Cuts:
- PID
- ≥ 1 D^0 cand. via 3σ cut on $m_{\pi+ K-}$
- vertex fit
  - $\chi^2 < 5$
  - $|z| \leq 0.7$ mm
  - $|\rho| \leq 0.1$ mm
- $p_{lab}(\pi^{\pm})>1.2$ GeV

Background Rejection O(10^5) for h_c' Study



Any additional background for $^3F_4$?

Radiative decays of X(3872) ?

X(3872) → $J/\psi\,\gamma$ seen by Belle and BaBar
E_γ=772 MeV/c² (high → outside of our range here)
X(3872) → $\psi'\gamma$ evidence at BaBar, not confirmed by Belle
X(3872) → $\chi_{cJ}\gamma$ not seen yet

BUT from $^3F_4$ to X(3872)
$4^{++} \rightarrow 1^{++}$ forbidden
$4^{++} \rightarrow 1^{--}$ (e.g. ψ') suppressed by
angular momentum barrier
suppression (2L+1) = 7

How Can We Estimate $\overline{\text{p}}$p Cross Sections @ $\overline{\text{P}}$ANDA ?

Production
@ $\overline{\text{P}}$anda

$$\sigma[p\bar{p} \to X(3872)] = \sigma_{BW}[p\bar{p} \to X(3872) \to \text{all}](m_{X(3872)})$$

$$= \frac{(2J+1)\cdot 4\pi}{m^2_{X(3872)} - 4m_p^2} \cdot \frac{\mathcal{B}(X(3872) \to p\bar{p}) \cdot \overbrace{\mathcal{B}(X(3872) \to f)}^{=1} \cdot \Gamma^2_{X(3872)}}{\underbrace{4(m_{X(3872)} - m_{X(3872)})^2}_{=0} + \Gamma^2_{X(3872)}}$$

$$\overset{(J=1)}{=} \frac{3 \cdot 4\pi}{m^2_{X(3872)} - 4m_p^2} \cdot \mathcal{B}(X(3872) \to p\bar{p})$$

Decay
@ Belle, BaBar, Bes3, LHCb

Cross Section Estimates from detailed balance

Table: Peak cross sections $\sigma^{\text{peak}}_{[p\bar{p}\to R]}$ for $p\bar{p} \to R$ assuming Breit Wigner distributions with constant small width Γ_R.

Res. R	J	Mass m [MeV]	$\mathcal{B}(R \to p\bar{p})$	$\sigma^{\text{peak}}_{[p\bar{p}\to R]}$ ±err. fr. $\mathcal{B}(R \to p\bar{p})$± err. fr. m_R
$J/\psi(1S)$	1	3096.916 ± 0.011	$(2.17 \pm 0.07) \cdot 10^{-3}$	$5.25 \pm 0.17 \pm 0.00\,\mu\text{b}$
$\psi(2S)$	1	$3686.109^{+0.012}_{-0.014}$	$(2.76 \pm 0.12) \cdot 10^{-4}$	$402 \pm 18 \pm 4\,\text{nb}$
$\eta_c(1S)$	0	2981.0 ± 1.1	$(1.41 \pm 0.17) \cdot 10^{-3}$	$1.29 \pm 0.16 \pm 0.00\,\mu\text{b}$
$\eta_c(1S)$	0	2981.0 ± 1.1	$(1.32 \pm 0.19) \cdot 10^{-3}$	$1.21 \pm 0.17 \pm 0.00\,\mu\text{b}$
$\eta_c(2S)$	0	3638.9 ± 1.3	$(1.85 \pm 1.26) \cdot 10^{-4}$	$93 \pm 63 \pm 0\,\text{nb}$
$\eta_c(2S)$	0	3638.9 ± 1.3	$(3.12 \pm 1.65) \cdot 10^{-4}$	$< 157 \pm 83 \pm 0\,\text{nb}$ (95% CL)
$\chi_{c0}(1P)$	0	3414.75 ± 0.31	$(2.23 \pm 0.13) \cdot 10^{-4}$	$134.1 \pm 7.8 \pm 0\,\text{nb}$
$h_c(1P)$	1	3525.41 ± 0.16	$(8.95 \pm 5.21) \cdot 10^{-4}$	$1.47 \pm 0.86 \pm 0\,\mu\text{b}$
$h_c(1P)$	1	3525.41 ± 0.16	$(1.68 \pm 0.05) \cdot 10^{-3}$	$< 2776 \pm 87 \pm 0\,\text{nb}$ (95% CL)
$X(3872)$	1	3871.68 ± 0.17	$(5.31 \pm 0.00) \cdot 10^{-4}$	$< 68.0 \pm 4.0 \pm 0.0\,\text{nb}$ (95% CL)
$X(3915)$	?	3917.5 ± 2.7	$(27 \pm 10) \cdot 10^{-3}$	not isolated

from PDG
from LHCb, arXiv:1303.7133 [hep-ex]
from combination of both (product branching fractions)

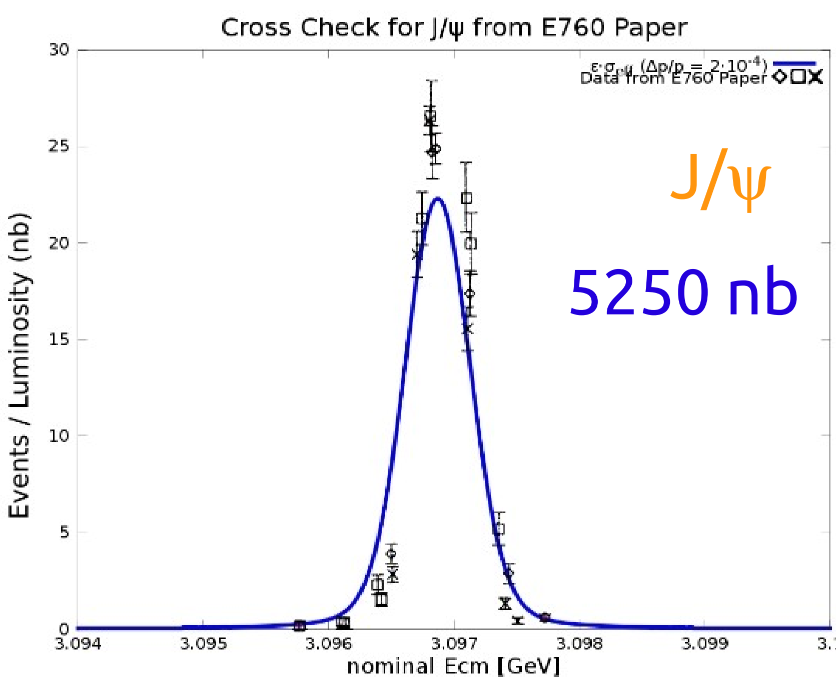
Check of cross section, derived from detailed balance

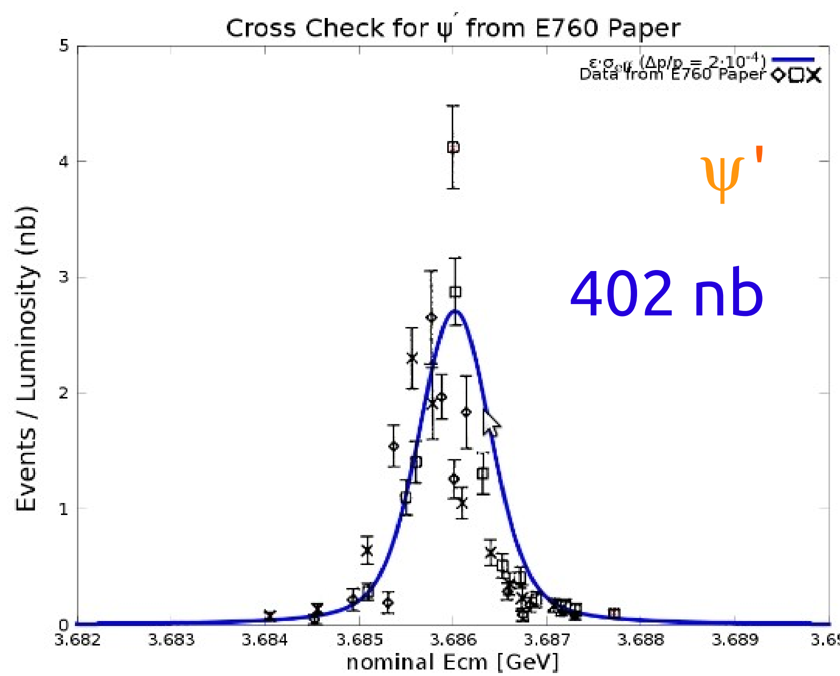
(blue line)

with direct measurement of J/ψ, ψ'

E760, Phys. Rev. D47(1993)772

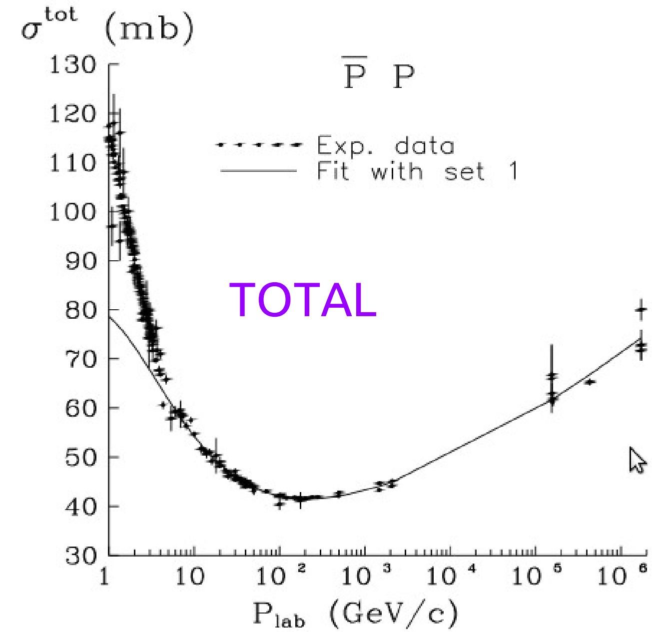
(data points)

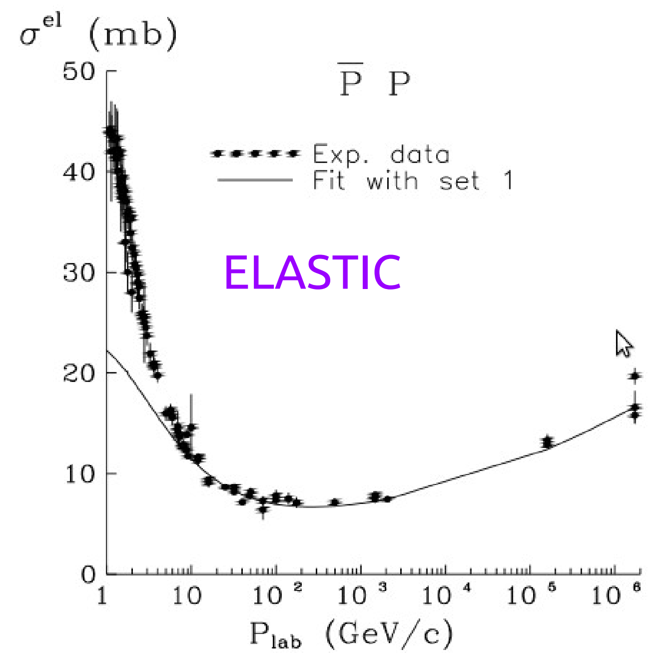


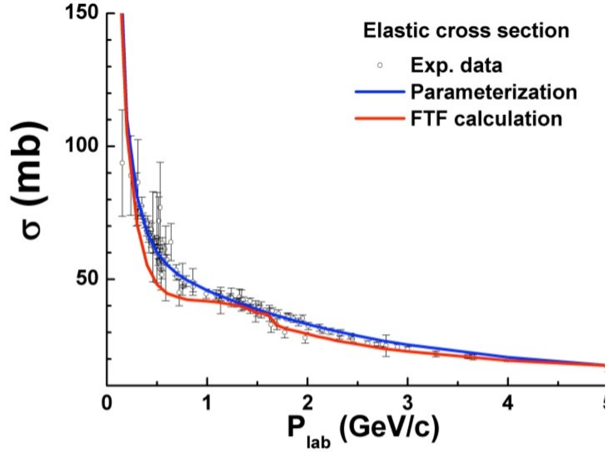


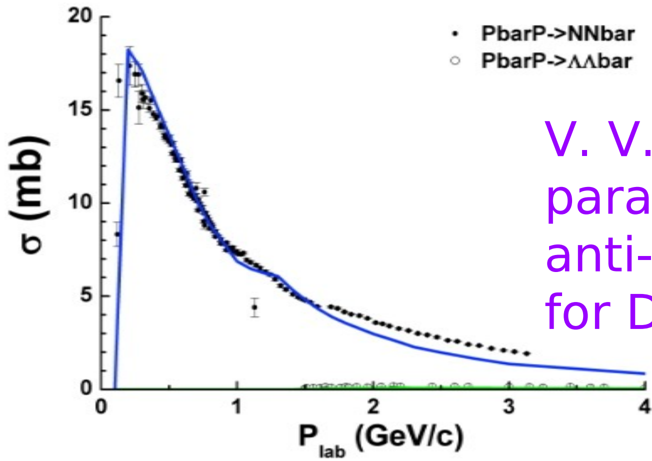
BACKGROUND
DPM
(Dual Parton Model)

A. Capella, U. Sukhatme, C.-I. Tan, J. Tran Thanh Van
Phys. Rept. 236, 225 (1994)
A. B. Kaidalov, P. E. Volkovitsky
Z. Phys. C63, 517 (1994)
V. V. Uzhinsky and A. S. Galoyan,
hep-ph/0212369

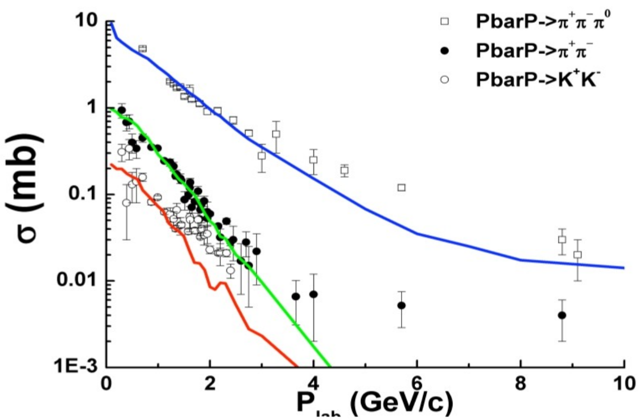


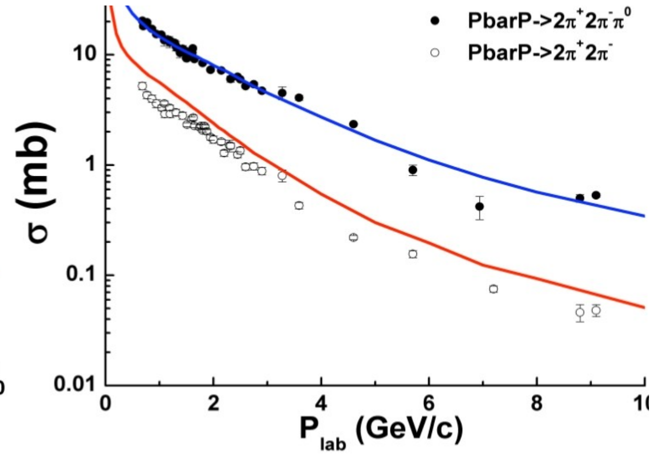


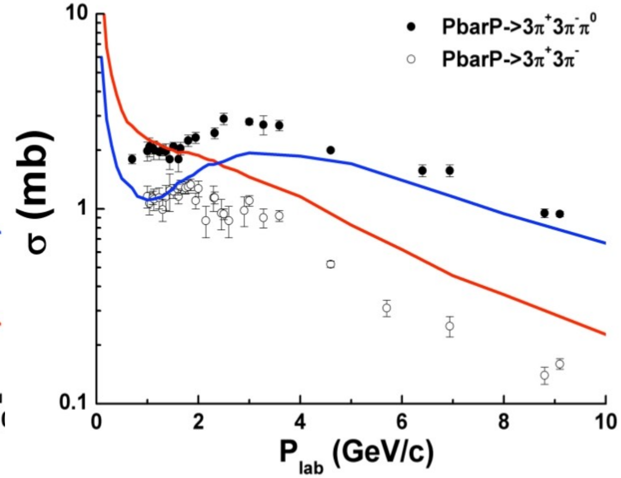


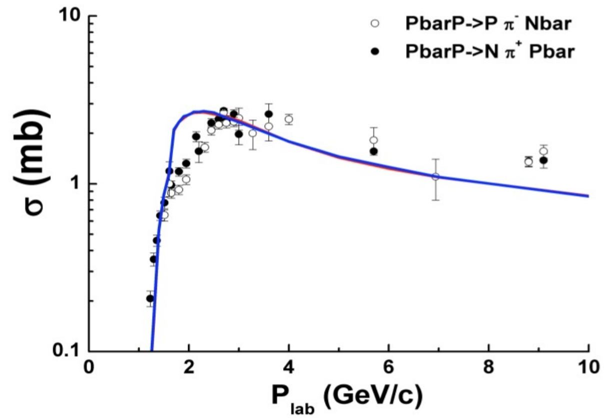


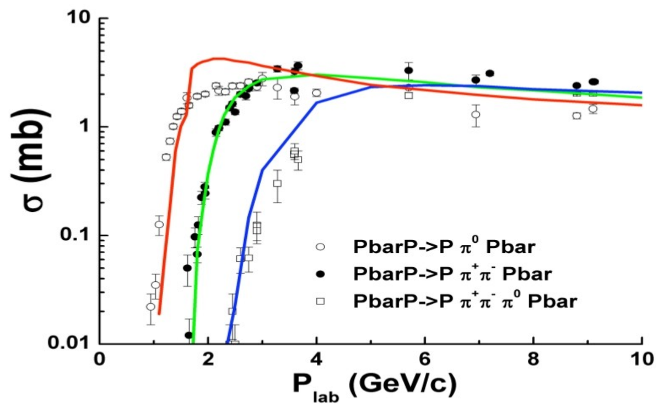
V. V. Uzhinsky, A. S. Galoyan
parametrization of
anti-proton cross sections
for DPM and Geant4









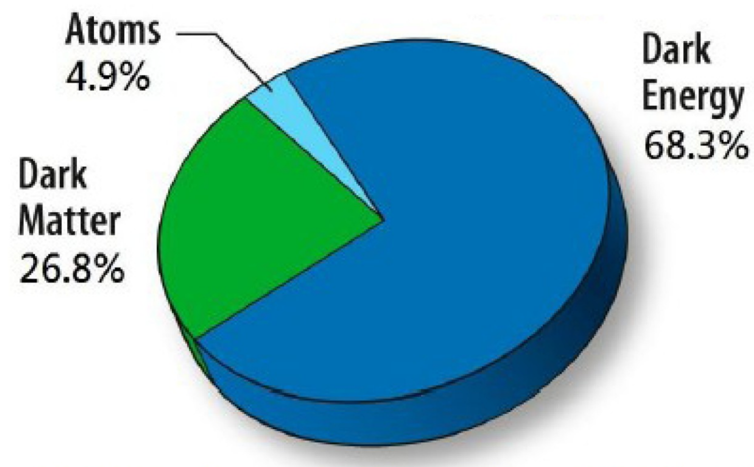


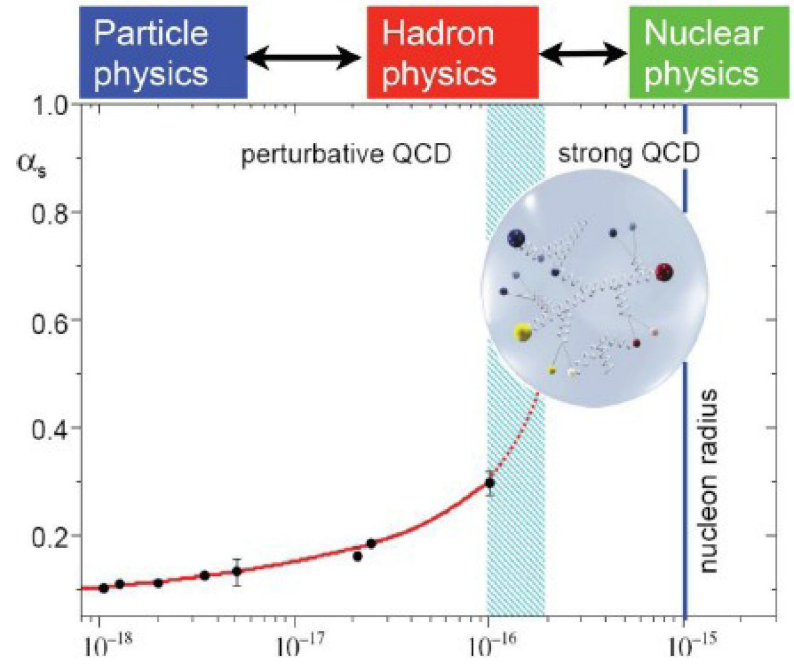
Motivation: the physics case

Understanding confinement
Origin of hadron masses

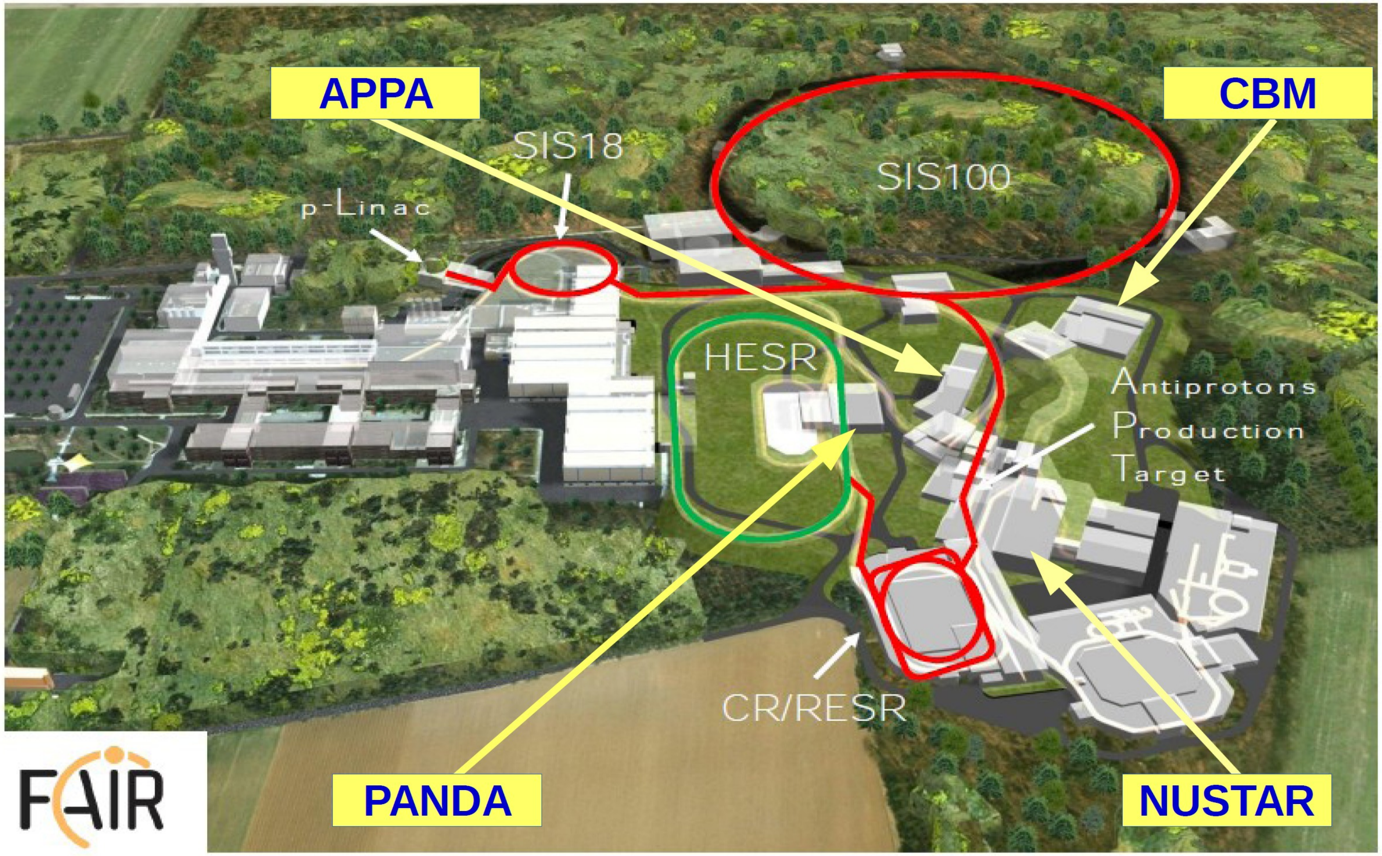
through the study of

- Hadron spectroscopy
  - Search for gluonic excitations
  - Charmonium spectroscopy
  - D meson spectroscopy
  - Baryon spectroscopy
  - QDC dynamics
- Nucleon structure
  - Parton distributions
  - Time-like form factors of the proton
  - Transition distribution amplitudes
  - Generalized distribution amplitudes
- Hadrons in matter
- Hypernuclei





Facility for Antiproton and Ion Research



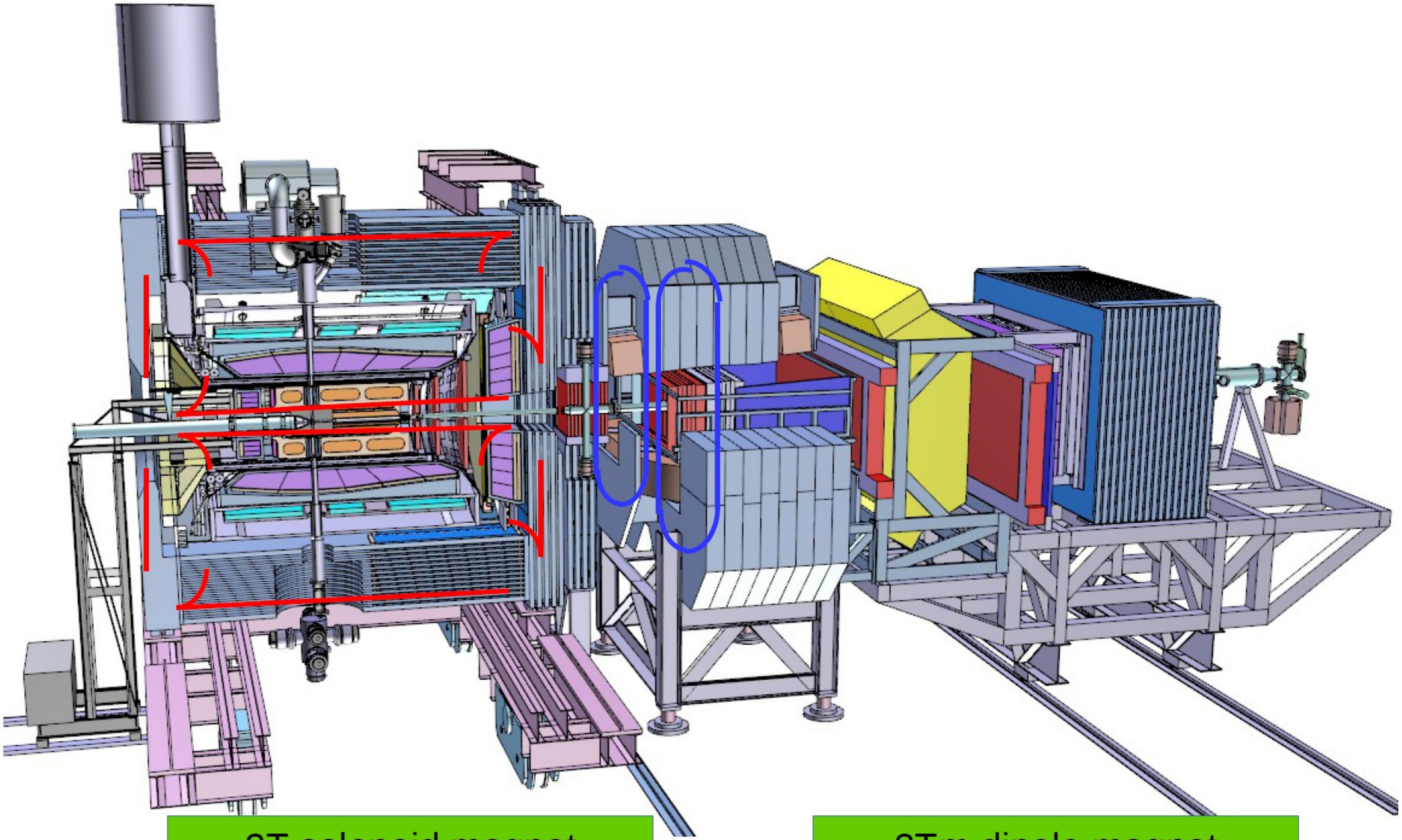
3000 Physicists
50 Countries

Scientific pillars of FAIR:
1. **A**tomic, **P**lasma **P**hysics and **A**pplications – APPA
2. **C**ompressed **B**aryonic **M**atter – CBM
3. **NU**clear **ST**ructure, **A**strophysics and **R**eactors – NUSTAR
4. anti**P**rotons **AN**nihilation at **DA**rmstadt - $\overline{\text{P}}$ANDA

A bird view of the site

Total area > 200 000 m^2
Area buildings = 98 000 m^2
Usable area = 135 000 m^2

The detector $\overline{\text{P}}$ANDA @ FAIR

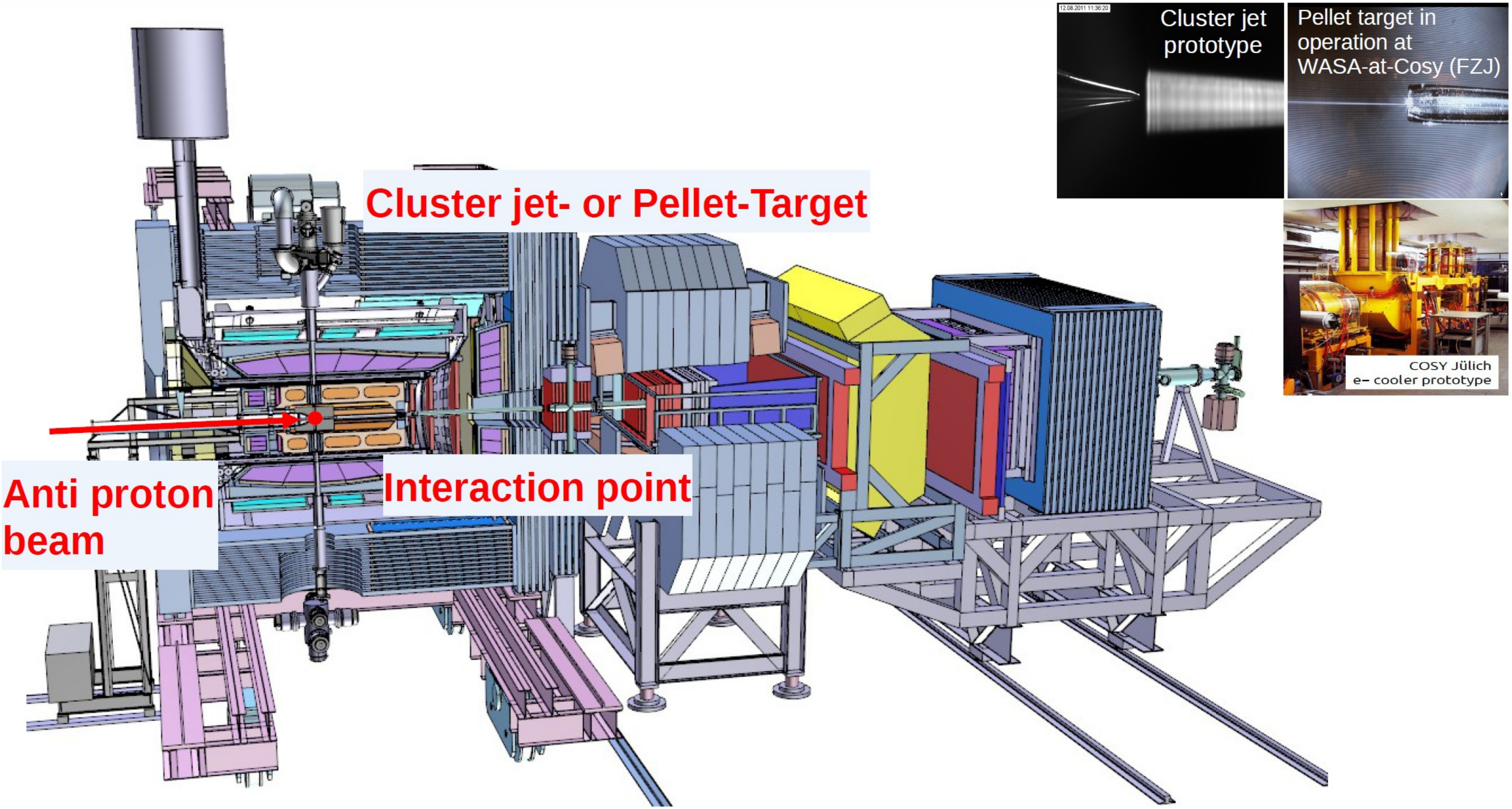


2T solenoid magnet

2Tm dipole magnet

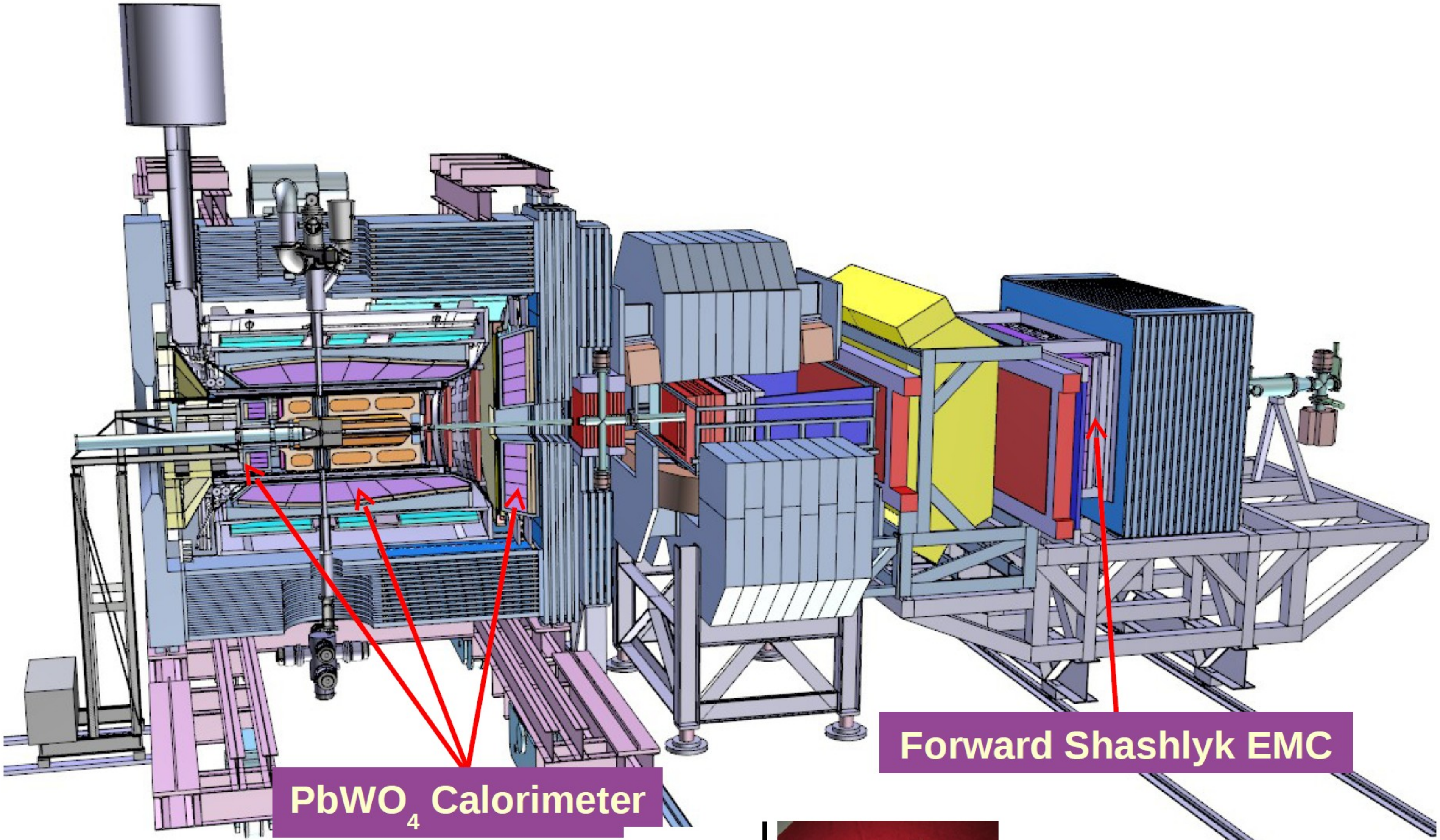
Magnet system

The detector $\overline{\text{P}}$ANDA @ FAIR

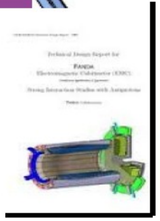


Target system: TDR approved for cluster jet
Prototype under construction

The detector $\overline{\text{P}}$ANDA @ FAIR

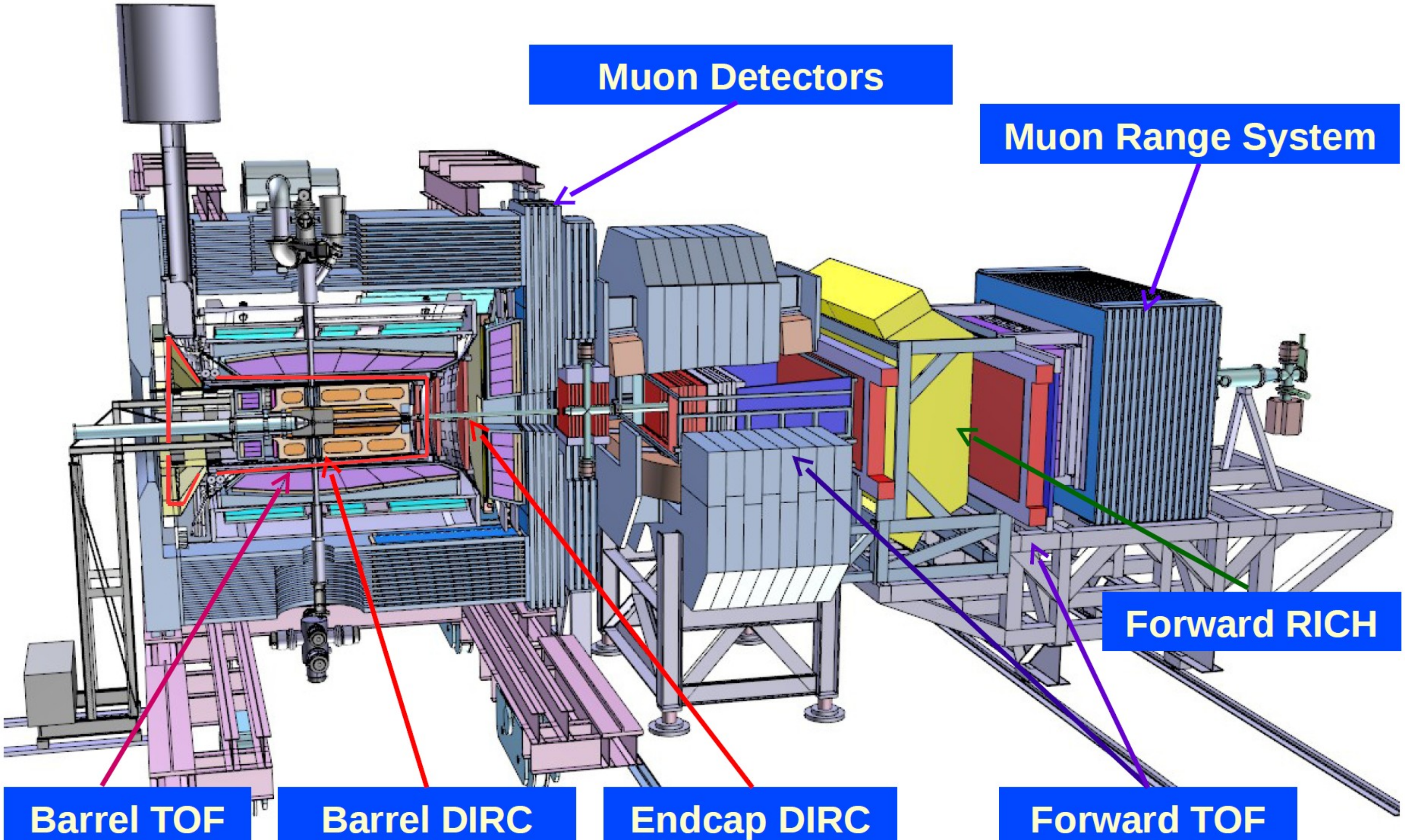


Calorimeters:
All endcap crystals produced
TDR approved



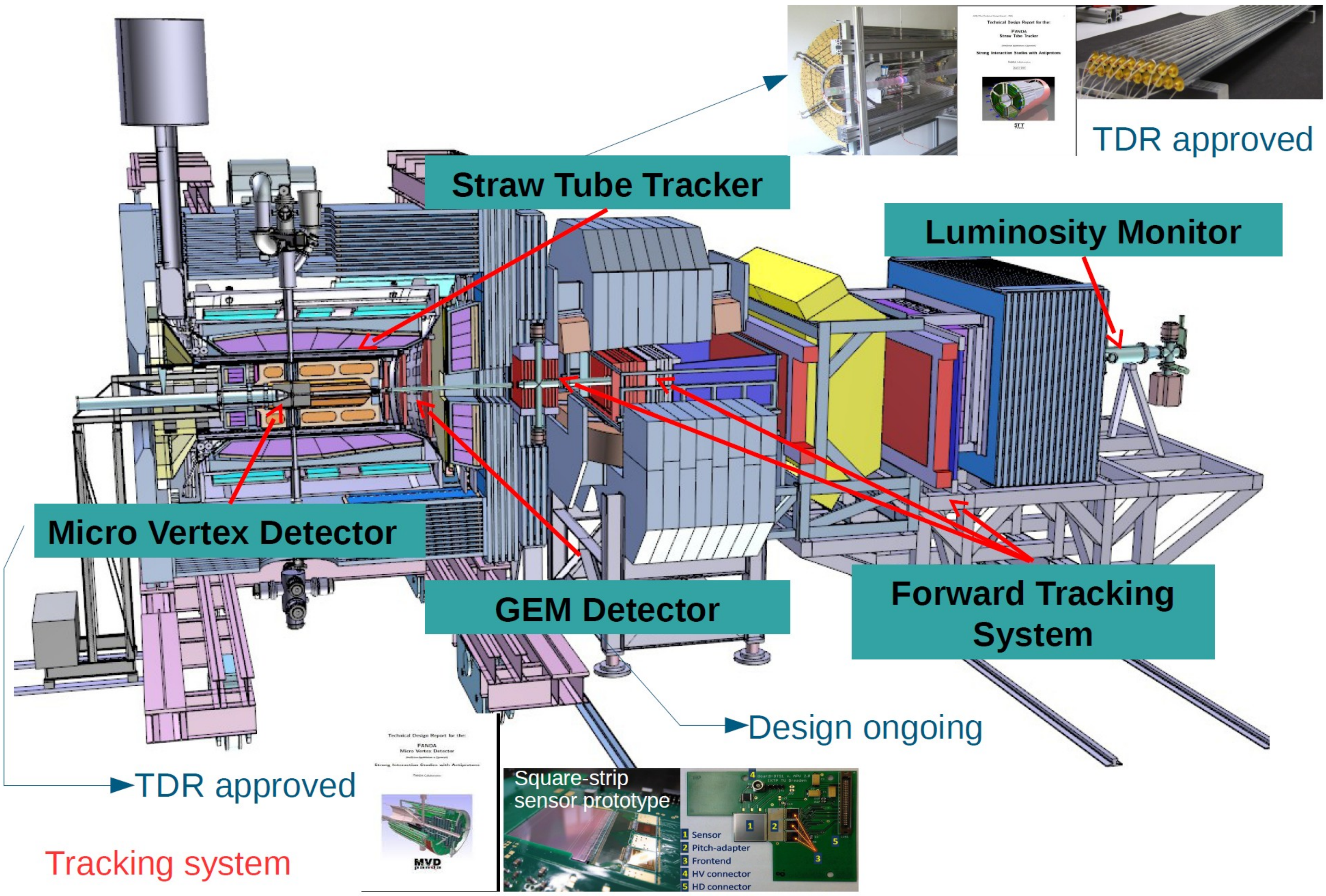
Courtesy of E. Prencipe, ICHEP 2014

The detector $\overline{\text{P}}$ANDA @ FAIR



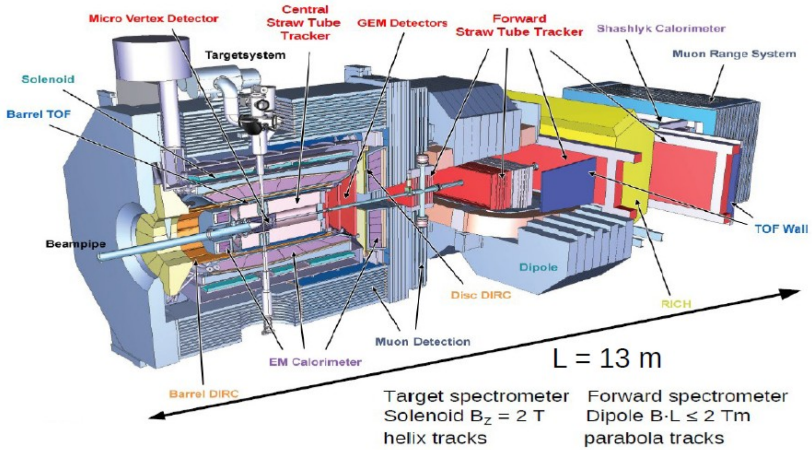
PID system

The detector P̄ANDA @ FAIR



The detector $\overline{P}$ANDA @ FAIR

- $\overline{P}$ANDA is a fixed target detector
  - ❍ High boost $\beta_{cms} \geq 0.8$
  - ❍ Many tracks and photons in fwd acceptance ($\theta \leq 30°$) (high p_z, E_γ)



- High background from hadronic reactions
  - ❍ Expected S/B ~ 10^{-6}
  - ❍ S (signal) and B (background) have same signature
  - ❍ Hardware trigger not possible
  - ❍ Self-triggered electronics
  - ❍ Free streaming data
  - ❍ 20 MHz interaction rate
  - ❍ Complete real-time event reconstruction