News in Quarkonium Production, and beyond

J.P. Lansberg

IPN Orsay – Paris-Sud U. – Paris Saclay U. –CNRS/IN2P3

9th France-China Particle Physics Laboratory Workshop

IPHC, Strasbourg, March 30 - April 1, 2016

April 1st, 2016

Our FCPPL collaboration

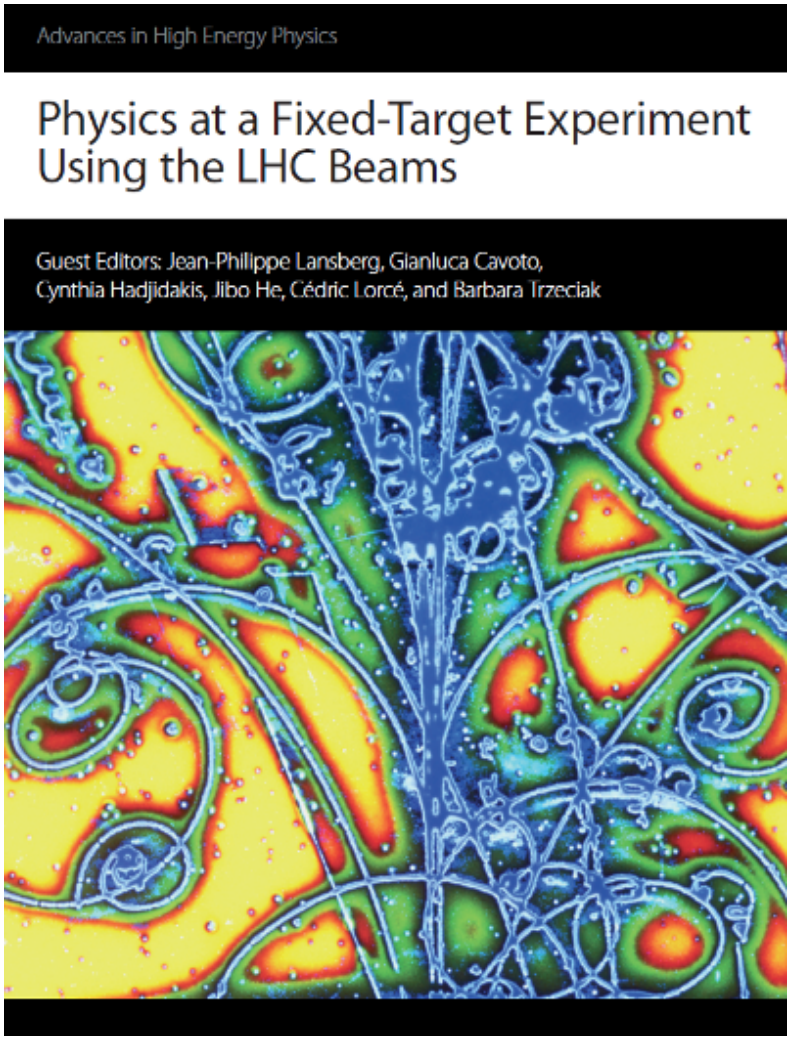
Theory of quarkonia + fixed-target experiment at the LHC

	France	China
Leaders	J.P. Lansberg (IPNO)	J.X. Wang (IHEP)
Permanent	C. Hadjidakis (IPNO) I. Hrivnacova (IPNO) C. Lorcé (CPhT-X)	B. Gong (IHEP) K.T. Chao (PKU) Y. Mao (PKU) Y.Q. Ma (PKU) Y. Gao (Tsinghua) Z. Yang (Tsinghua) Z. Tang (USTC)
Non-permanent	L. Massacrier (IPNO & LAL) F. Scarpa (IPNO)	L.P. Sun (PKU)

Realisations (1)

Edition of a special issue in Adv. High. Energy Physics

- Dedicated to the physics opportunities with a fixed-target set-up on the LHC beams
- Editors included JPL, C. Hadjidakis (IPNO), C. Lorcé , J. He (UCAS-Beijing)
- The issue includes 15 refereed papers



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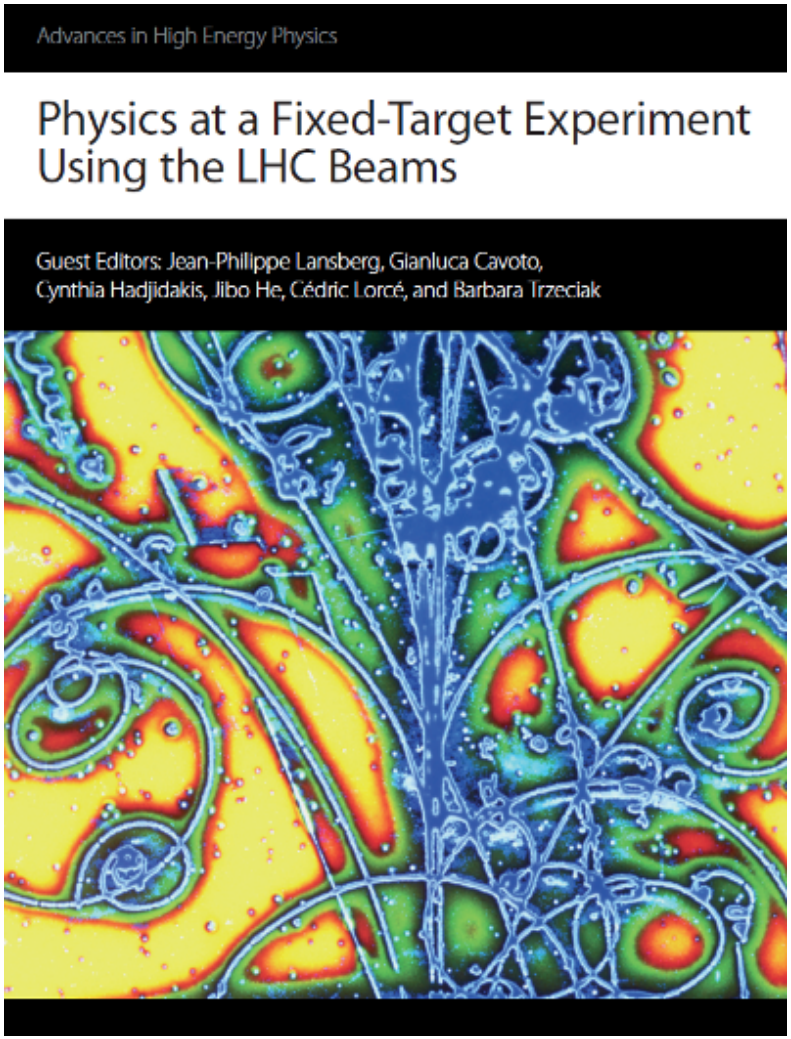
  - J.X Wang and Y. Feng (IHEP): NLO quarkonium production x-section
  - P.F Zhang (Tsinghua) : charm regeneration contribution at 72 GeV
  - H.S. Shao (Ex PKU), C. Hadjidakis, L. Massacrier, JPL: First onium simulations (see next slide)



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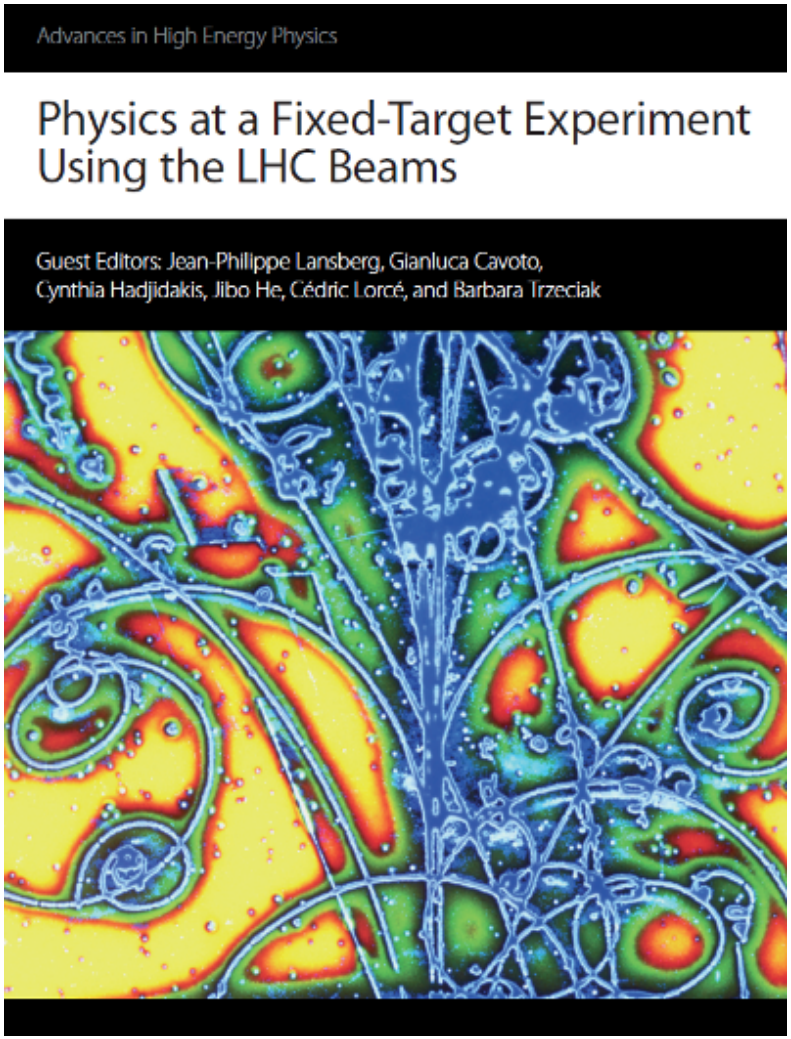
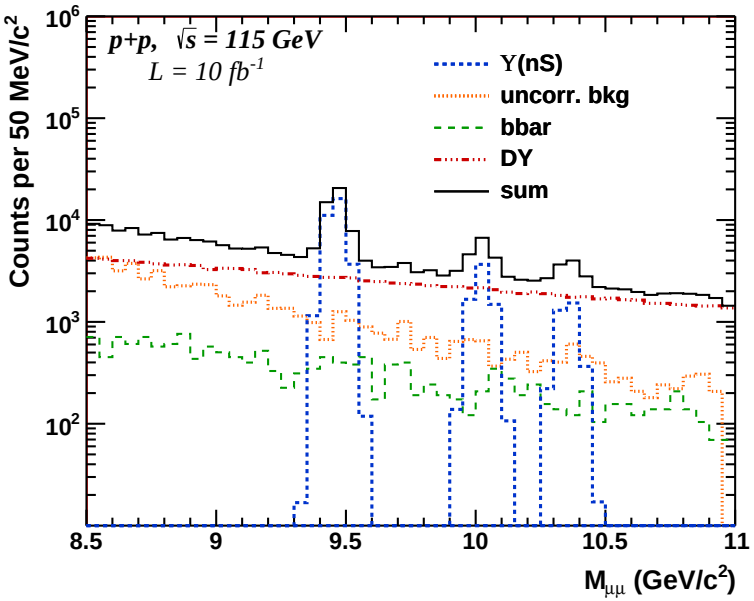
  - H.S. Shao (Ex PKU), C. Hadjidakis, L. Massacrier, JPL: First onium simulations (see next slide)
- In parallel, we are drafting an Expression of Interest for AFTER@LHC
  - 3 workshops this year (Warsaw, Orsay, Freudenstadt)
  - 30+ direct contributors
  - 3 physics cases: high-x, spin and heavy-ion physics



Realisations (2)

Ex: Simulations of the bottomonium background & signal reach with a LHCb-like detector

B. Trzeciak, L. Massacrier, .., JPL, .., H.S. Shao, Adv.Hi.En.Phys. (2015) 986348



The dominant background is Drell-Yan

3 peaks well resolved

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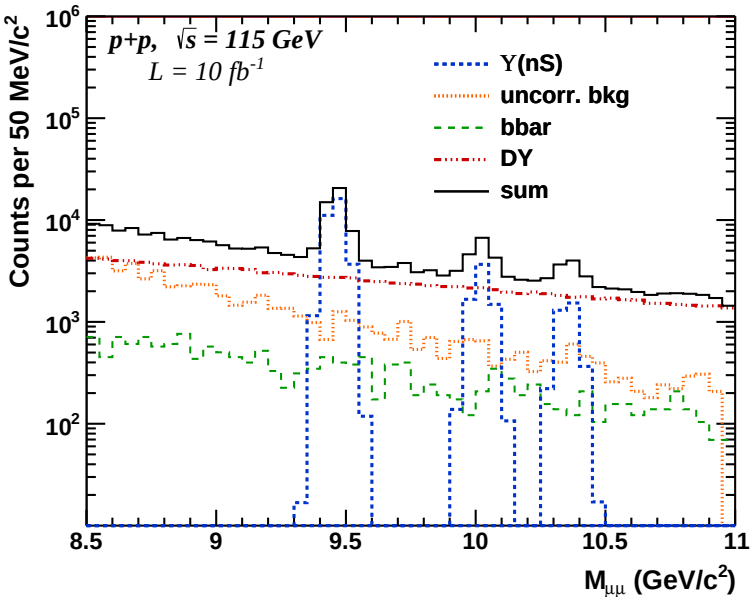

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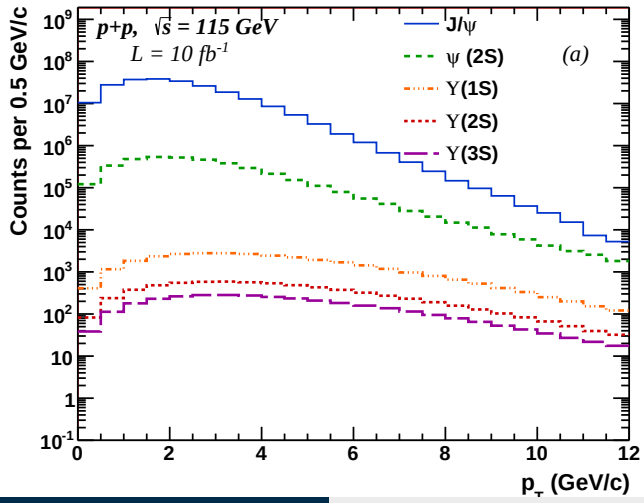
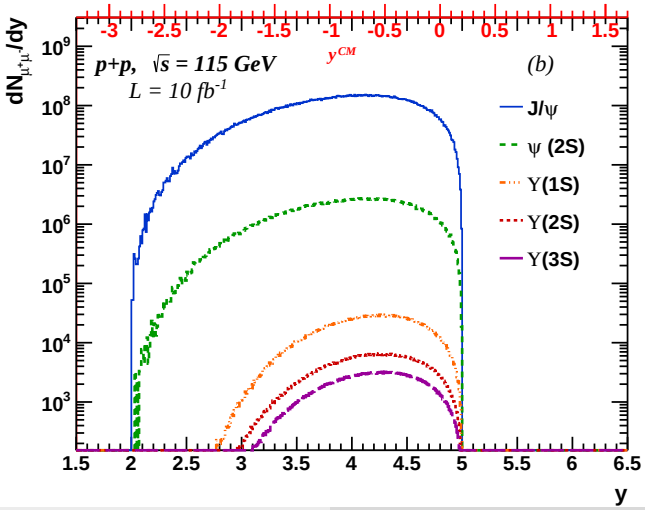
J/ψ: 10^4 events at $P_T \simeq 12$ GeV

Υ : 200 events at $P_T \simeq 12$ GeV





J/ψ: reach cut by the detector acceptance

Υ : 200 events at $y^{\Upsilon}_{c.m.s.} \simeq -2.1$, i.e. $x_2 \simeq 0.7$

Realisations (3)

First full one loop analysis of quarkonium total cross sections [part of the PhD of Y.Feng]

Eur. Phys. J. C (2015) 75:313
DOI 10.1140/epjc/s10052-015-3527-1

THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Theoretical Physics

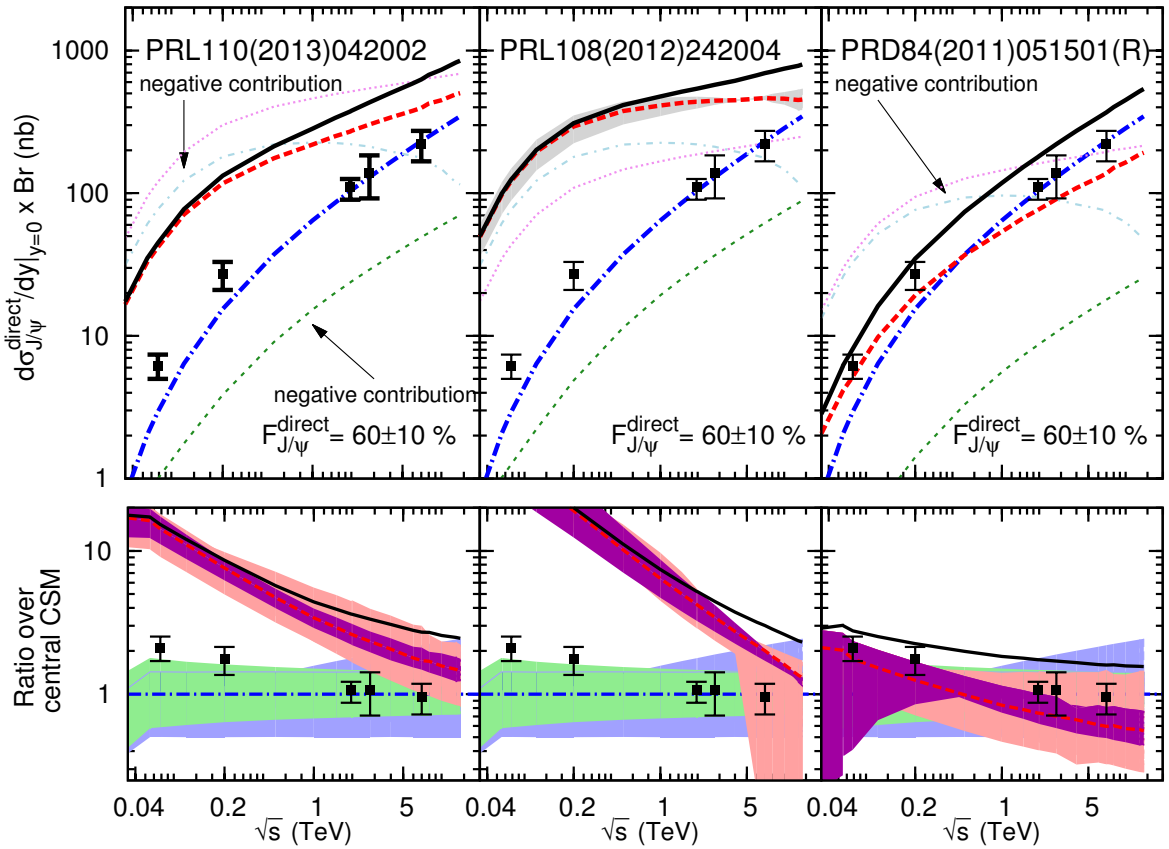
Energy dependence of direct-quarkonium production in pp collisions from fixed-target to LHC energies: complete one-loop analysis

Yu Feng[1,2], **Jean-Philippe Lansberg**[3,a], **Jian-Xiong Wang**[1,2]

[1] Institute of High Energy Physics, CAS, P.O.Box 918(4), Beijing 100049, China
[2] Theoretical Physics Center for Science Facilities, CAS, Beijing 100049, China
[3] IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France

Abstract We compute the energy dependence of the P_T-integrated cross section of directly produced quarkonia in pp collisions at next-to-leading order (NLO), namely up to α_S^3, within nonrelativistic QCD (NRQCD), treating the P_T-*integrated* and the P_T-*differential* cross sections as two different observables. The colour-octet NRQCD parameters needed to predict the P_T-integrated yield can thus be extracted from the fits of the P_T-differential cross sections at mid and large P_T. For the first time, the total cross section is evaluated in NRQCD at full NLO accuracy using the recent NLO fits of the P_T-differential yields. Both the normalisation and the energy dependence of the J/ψ, ψ' and $\Upsilon(1S)$ we obtained disagree with the data except when using the fit results of Butenschoen and Kniehl. If one disregards the colour-octet contribution, the existing data in the TeV range are well described by the α_S^3 contribution in the colour-singlet model – which, at α_S^4, however, shows an unphysical energy dependence. A similar observation is made for $\eta_{c,b}$. All this underlines the necessity for a resummation of initial-state radiations in both channels, which is, however, beyond the scope of this article. In any case, past claims that colour-octet transitions are dominantly responsible for low-P_T quarkonium production are not supported by our results.

IHEP – PKU – Hamburg



Realisations (4)

New observables in quarkonium production

- Organisation of a workshop in Italy entirely dedicated to “New observables in quarkonium production”
- 45+ participants with a strong FCPPL participation
- First meeting aiming at gathering “spin” and “heavy-ion” quarkonium specialists
- We agreed to propose to edit a special issue on Few Body Systems (Springer)
  Agreed by the FBS editorial board;

  Deadline: Sept. 1st 2016

ECT*

EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS
TRENTO, ITALY
Institutional Member of the European Expert Committee NUPECC

Castello di Trento (“Trint”), watercolor 19.8 x 27.7, painted by A. Dürer on his way back from Venice (1495). British Museum, London

New observables in quarkonium production
Trento, 29 Feb 2016 to 04 Mar 2016

Main Topics
Quarkonium production remains one of the long standing puzzles of QCD. As such, it still deserves full attention from both experimentalists and theorists. The main topics of the workshop will be:

- Quarkonium production in *pp*, *pA* and *AA* collisions: where do we stand?
- Transverse Momentum Dependent factorisation in quarkonium production
- Associated quarkonium production and double-parton scatterings
- Excited-quarkonium production from *pp* to *AA* collisions
- Quarkonium-pair production: when TMDs meet Quark Gluon Plasma
- Experimental requirements for forthcoming measurements

Key Participants
M. Anselmino (Torino University and INFN), F. Arleo (Ecole polytechnique, Palaiseau), R. Arnaldi (INFN Torino), I. C. Arsene (University of Oslo), D. Boer (University of Groningen), R. Boussarié (LPT Orsay), M. Calderon de la Barca Sanchez (University of California Davis), I. Cherednikov (University of Antwerp), C. da Silva (Los Alamo National Lab), D. d’Enterria (CERN, Switzerland), B. Ducloué (University of Jyvaskyla), P. B. Gossiaux (SUBATECH, Nantes), C. Hadjidakis (IPN Orsay), V. Kartvelishvili (Lancaster University), T. Kasemets (Nikhef/VU, Amsterdam), D. Kikola (Warsaw University of Technology), L. Kratschmer (Hephy, Vienna), Y.-Q. Ma (Peking University), L. Massacrier (LAL and IPN Orsay), Z. E. Meziani (Temple U., Philadelphia) A. Mukherjee (IIT Bombay), P. Petreczky (Brookhaven National Lab), S. Porteboeuf (LPC, Clermont-Ferrand), D. Price (University of Manchester), J.W. Qiu (Brookhaven National Lab), A. Rakotozafindrabe (CEA/IRFU, Gif-sur-Yvette), K. Redlich (University of Wroclaw and Duke University), F. Scarpa, (IPN Orsay & University of Groningen), M. Schlegel (University of Tübingen), E. Scomparin (INFN Torino), H. S. Shao (CERN), P. Taels (University of Antwerp & CEA/IPHT, Gif-sur-Yvette), B. Trzeciak (Utrecht University), Z. Tang (University of Science and Technology of China, Hefei), A. Vairo (TUM, Munich), J. X. Wang (IHEP, Peking), K. Watanabe (Central China Normal University, Wuhan), M. A. Winn (Heidelberg University), H. F. Zhang (Chongqing University of Posts and Telecommunications), P. F. Zhuang (Tsinghua University, Peking).

Organisers
J.P. Lansberg (IPN Orsay, CNRS-IN2P3, Univ. Paris-Sud, Université Paris-Saclay, France)
T. Dahms (Excellence Cluster Universe - TUM, Munich, Germany)
E.G. Ferreiro (IGFAE, University of Santiago de Compostela, Spain)
C. Pisano (University of Antwerp, Belgium & University of Pavia, Italy)

Director of the ECT*: Professor Jochen Wambach (ECT*)

The ECT* is sponsored by the “Fondazione Bruno Kessler” in collaboration with the “Assessorato alla Cultura” (Provincia Autonoma di Trento), funding agencies of EU Member and Associated States and has the support of the Department of Physics of the University of Trento.

For local organization please contact: Gianmaria Ziglio - ECT* Secretariat - Villa Tambosi - Strada delle Tabarelle 286 - 38123 Villazzano (Trento) - Italy
Tel.:(+39-0461) 314721 Fax:(+39-0461) 314750, E-mail: **ect@ectstar.eu or visit http://www.ectstar.eu**

Realisations (5)

Our recent theory studies of new observables in quarkonium production

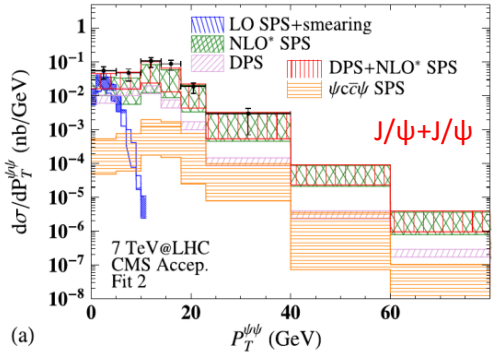
- **Quarkonium** (cc or bb) **production** is a **multiscale problem** involving both perturbative and nonperturbative aspects of QCD

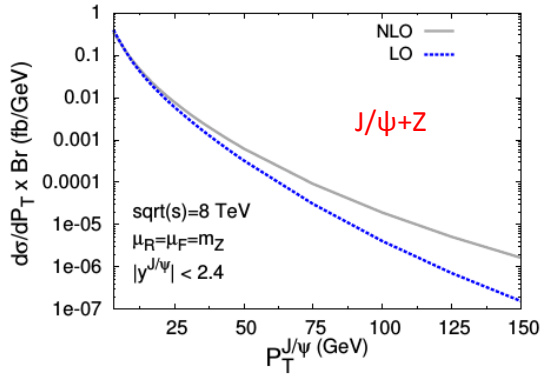
- Usual way to understand quarkonium dynamics : improve the precision of measurements and of theoretical predictions for their **yields and polarisation *alone***

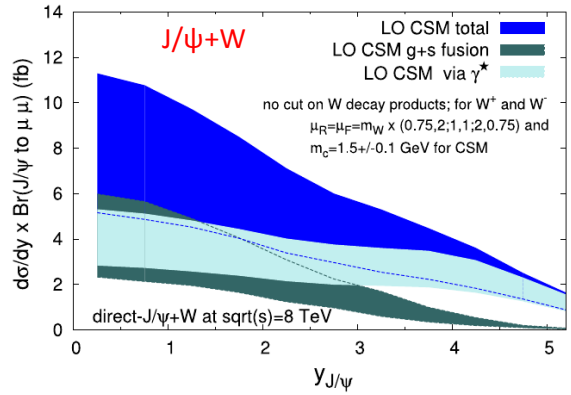
- We propose to look at **associated-production processes** which exhibit a **different sensitivity on different production channels** [octet vs singlet production]

- We recently studied (mostly at NLO):

  - J/ψ+W/Z then measured by ATLAS (LHC)
    JHEP 1303 (2013) 115 (with J.X. Wang); Phys.Lett. B726 (2013) 218
  - J/ψ+J/ψ then measured by D0 (Tevatron) and CMS (LHC)
    Phys.Rev.Lett. 111 (2013) 122001 ; Phys.Lett. B751 (2015) 479 (with H.S. Shao)
  - J/ψ+ϒ for AFTER@LHC
    Nucl.Phys. B900 (2015) 273 (with H.S. Shao)
  - J/ψ+γ for TMD studies
    Phys.Rev.Lett. 112 (2014) 212001







Projects (1)

Revisiting Associated quarkonium production at NLO

with Li-Ping SUN (PKU) and Hua-Sheng Shao (CERN, ex-PKU, future LPTHE)

We wish to perform new NLO studies of

- $\psi + \psi$ measured by LHCb, CMS, D0
- $\psi + W$ measured by ATLAS
- $\psi + Z$ measured by ATLAS
- $\psi + \Upsilon$ measured by D0
- $\psi + D$ measured by LHCb

with a different model as our previous studies (see previous slide)

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- $\psi + D$ measured by LHCb

with a different model as our previous studies (see previous slide)

- ATLAS results for $\psi + W$ and $\psi + Z$ show strong tensions with theory
- L.P. Sun came to Orsay last December to initiate the project
- First publication on $\psi + W$ and $\psi + Z$ very soon (curves already available)

Projects (2)

Simulations for Drell-Yan and D meson production in the fixed-target mode

with Z. Yang (Tsinghua) (possibly with J.He (UCAS))

- Using generic LHCb performances for muons [as done previously]
- Using background already recorded with LHCb-SMOG for D mesons

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- Using generic LHCb performances for muons [as done previously]
- Using background already recorded with LHCb-SMOG for D mesons
- Aim: Drell-Yan analysis in $pp^{\uparrow}$, pA and AB
- Performances eventually to be compared to a set-up using ALICE (with an absorber)

Discussions with A. Uras (IPNL), G. Martinez (Subatech)

- All this is motivated by the excellent prospects for an internal gas target

SMOG@LHCb: the first step towards an internal (polarised) target ?

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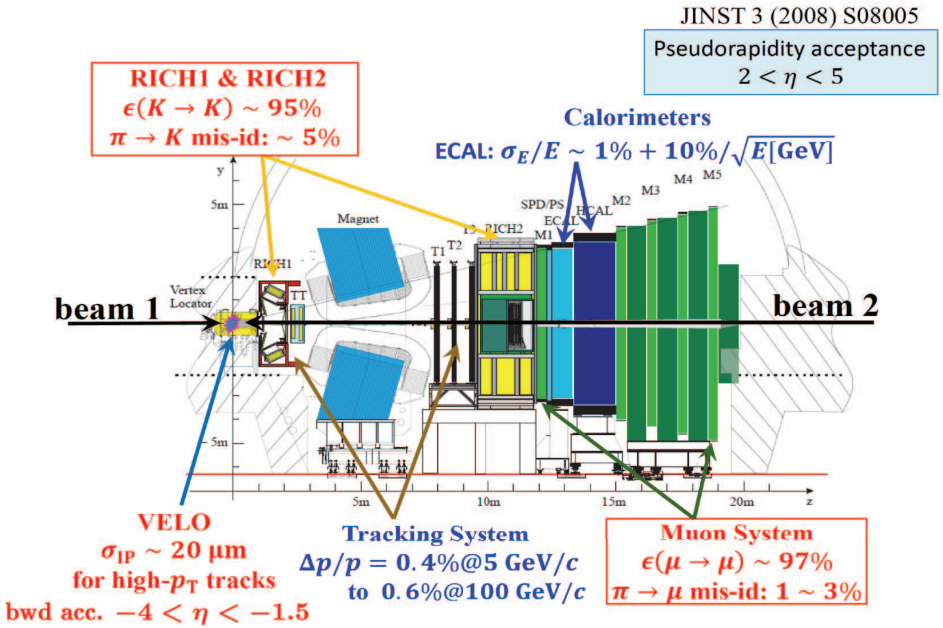
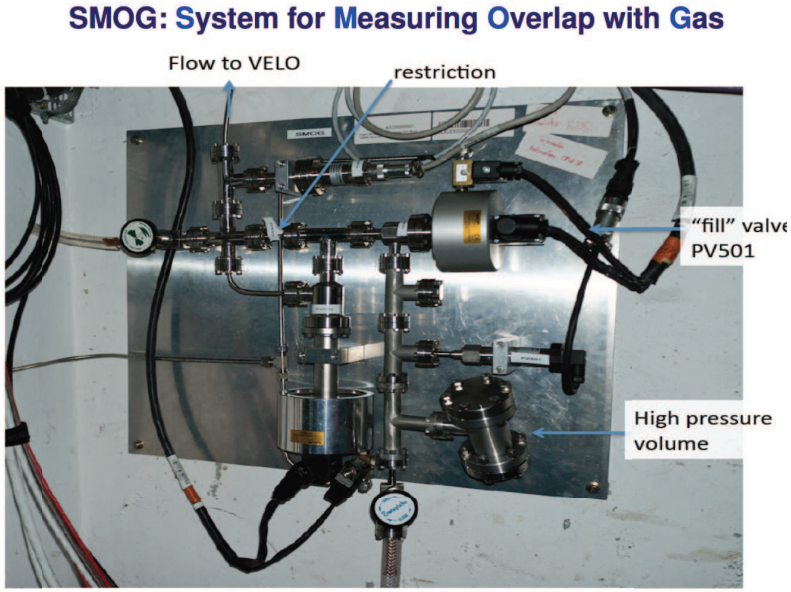
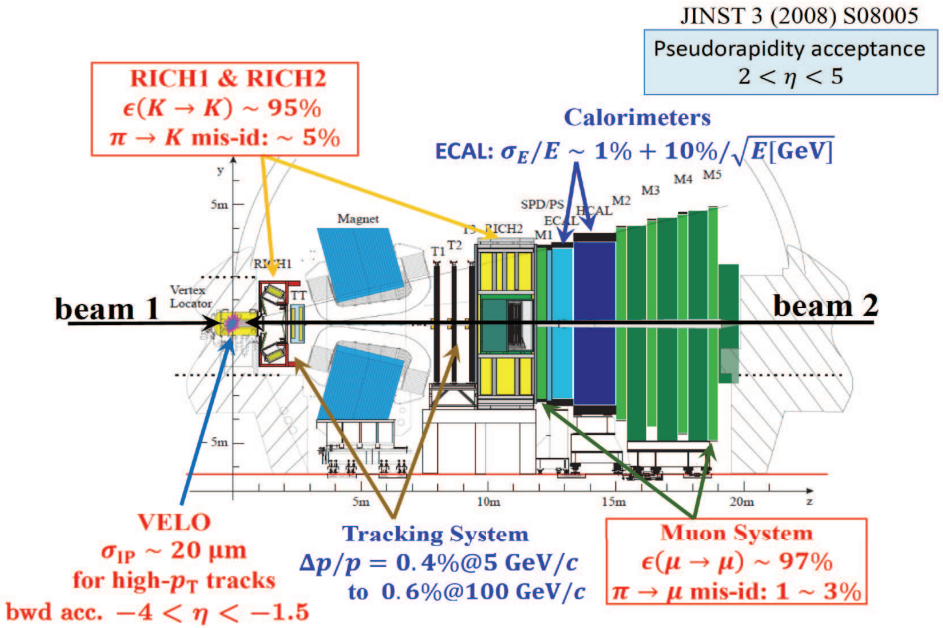
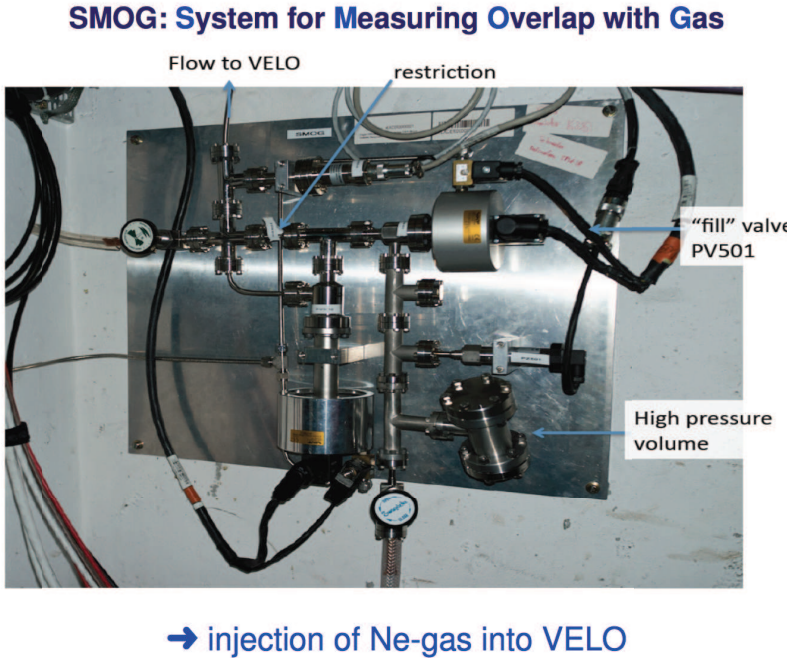




➜ injection of Ne-gas into VELO

SMOG@LHCb: the first step towards an internal (polarised) target ?





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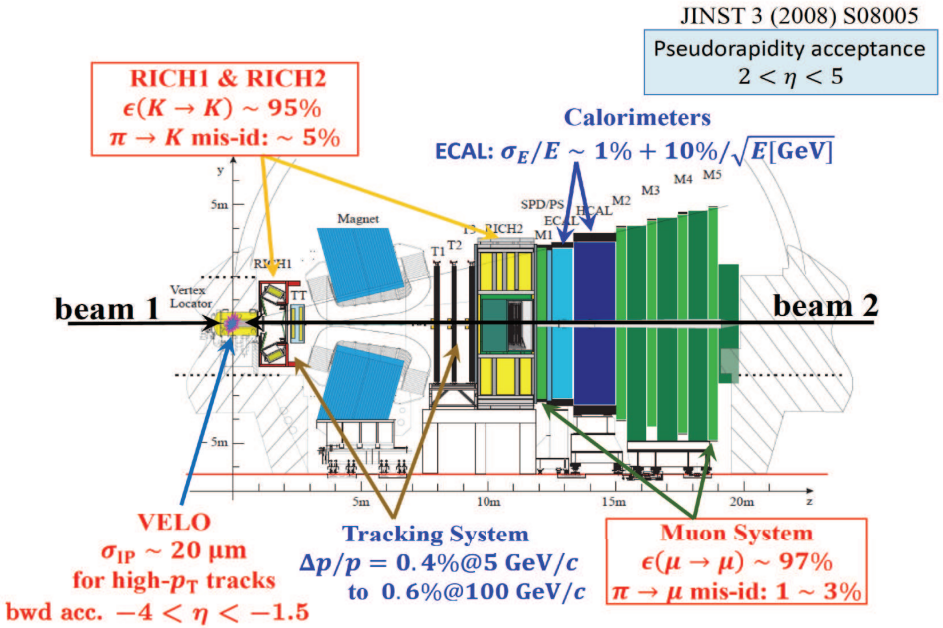

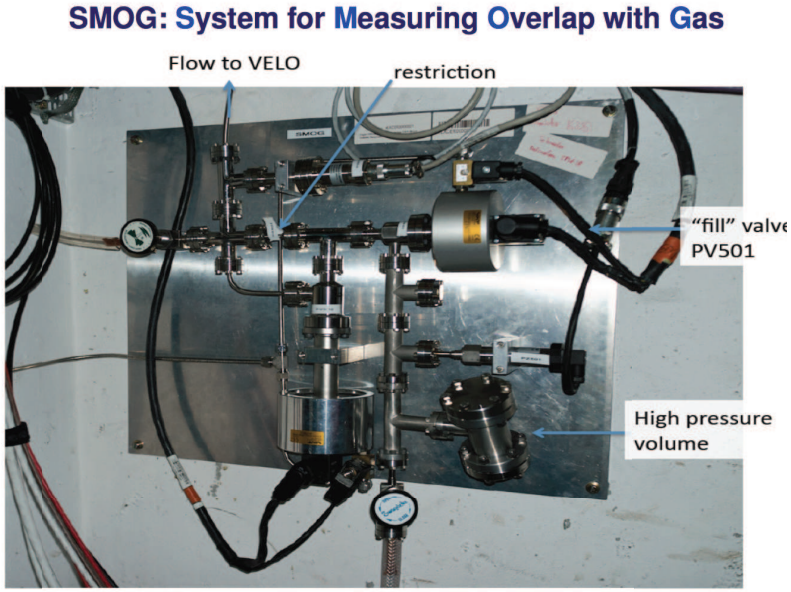

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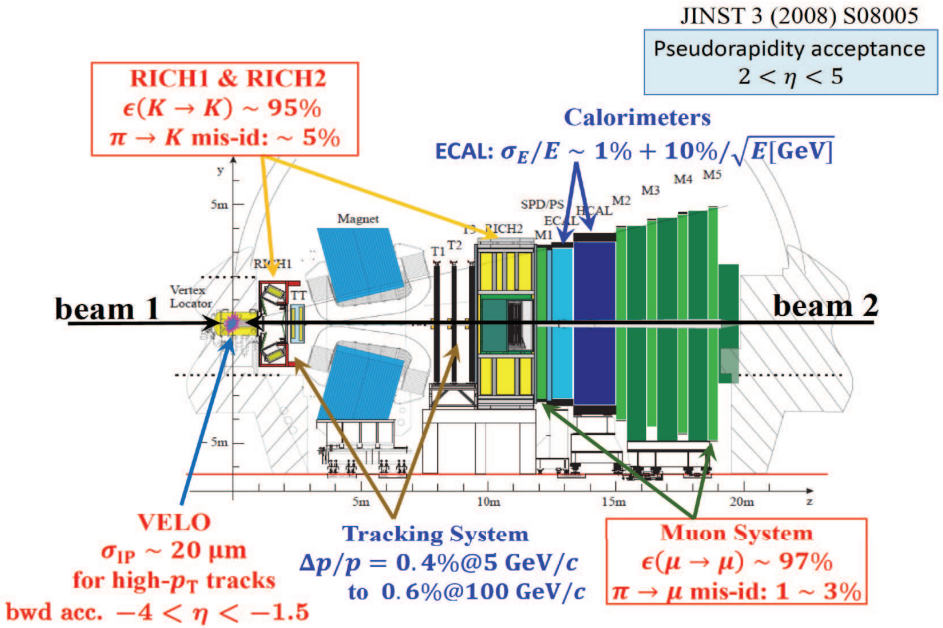

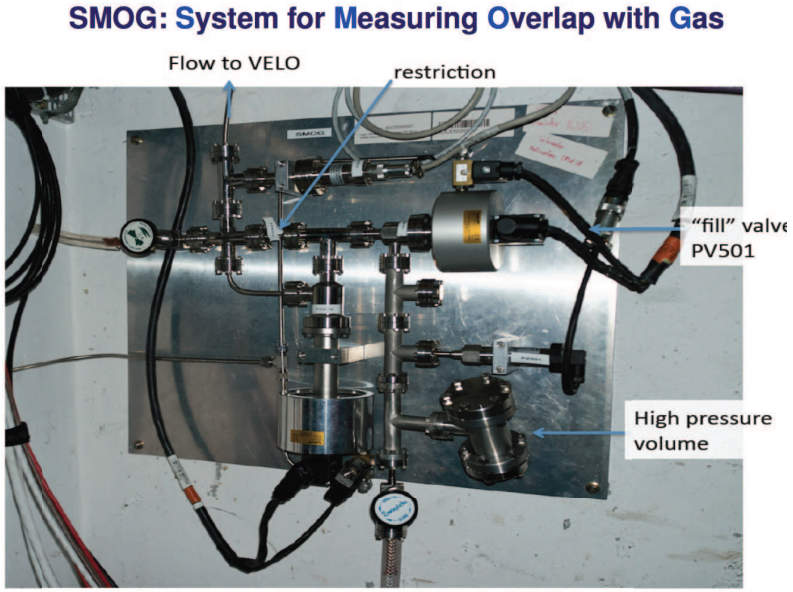

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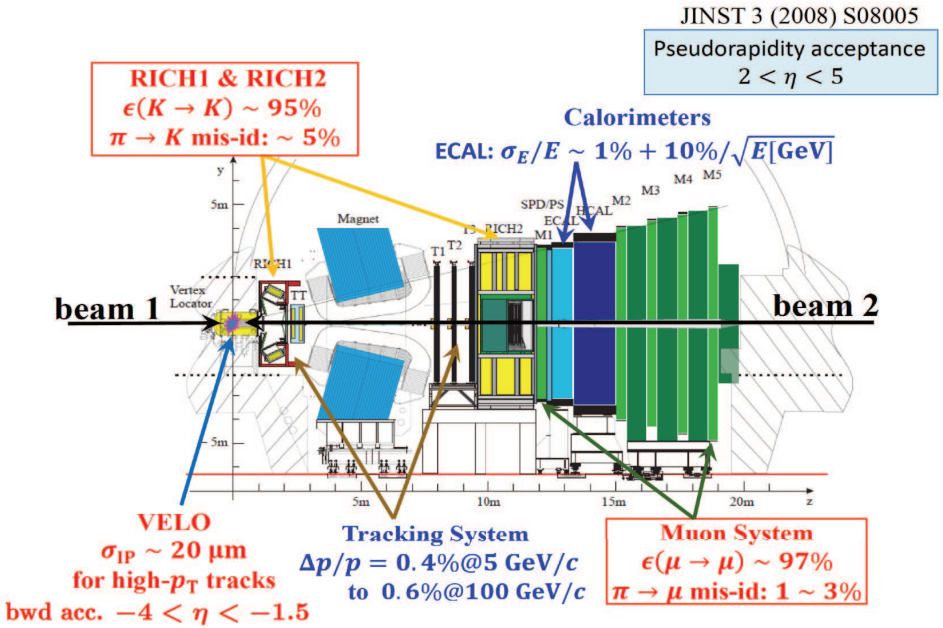

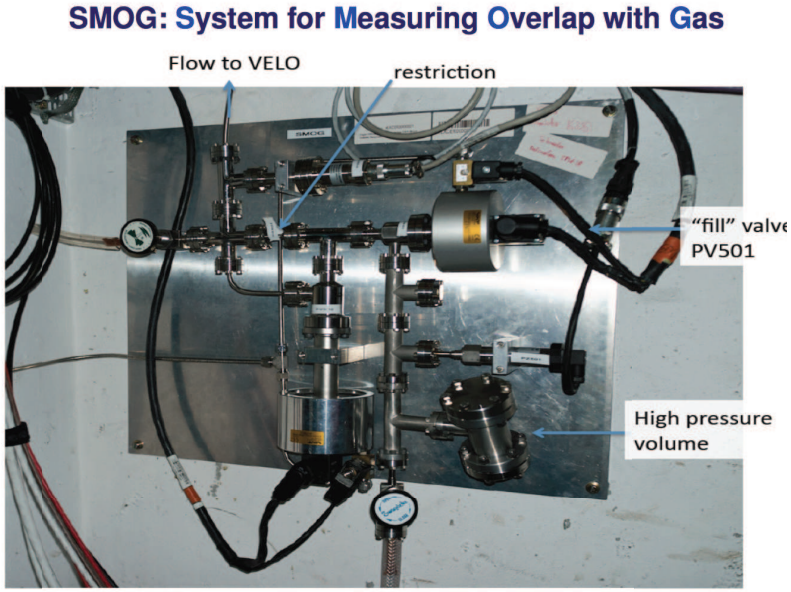

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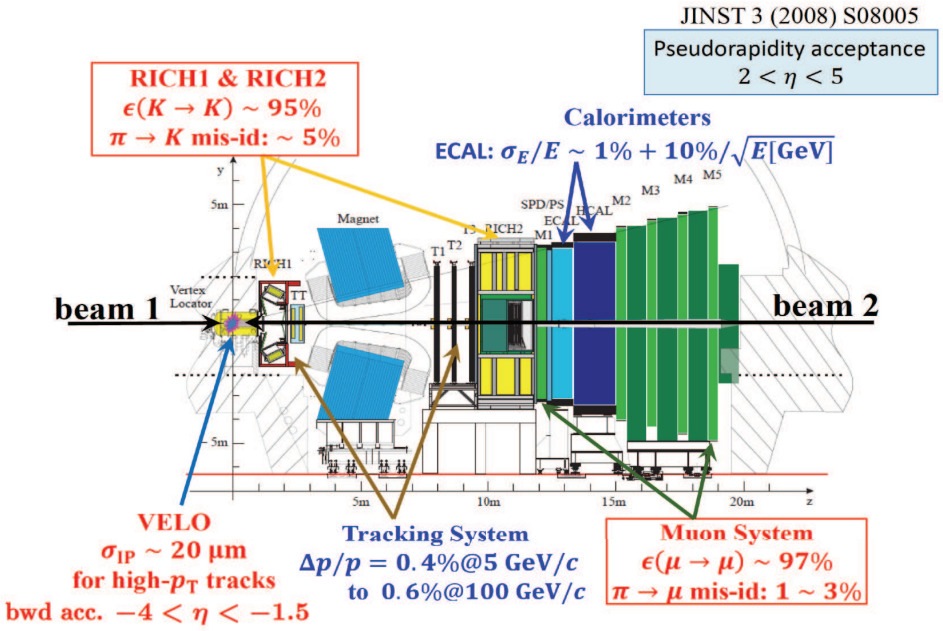

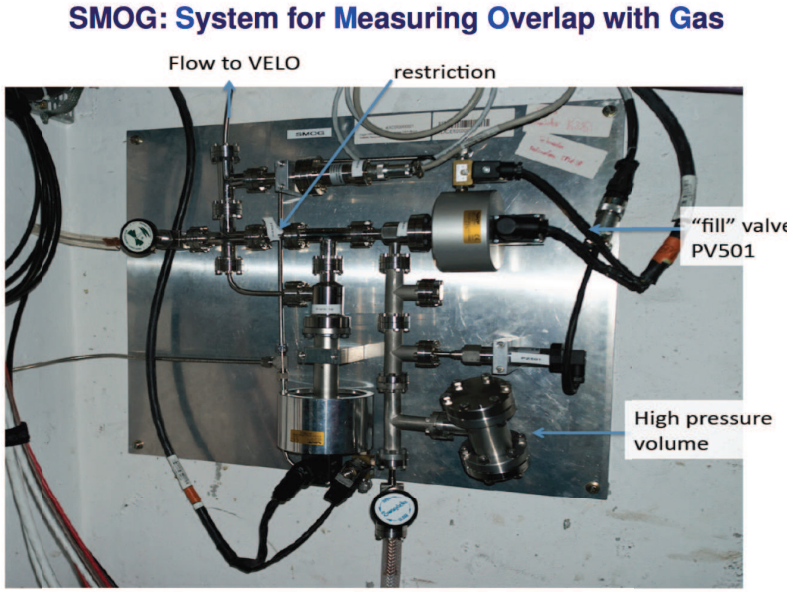

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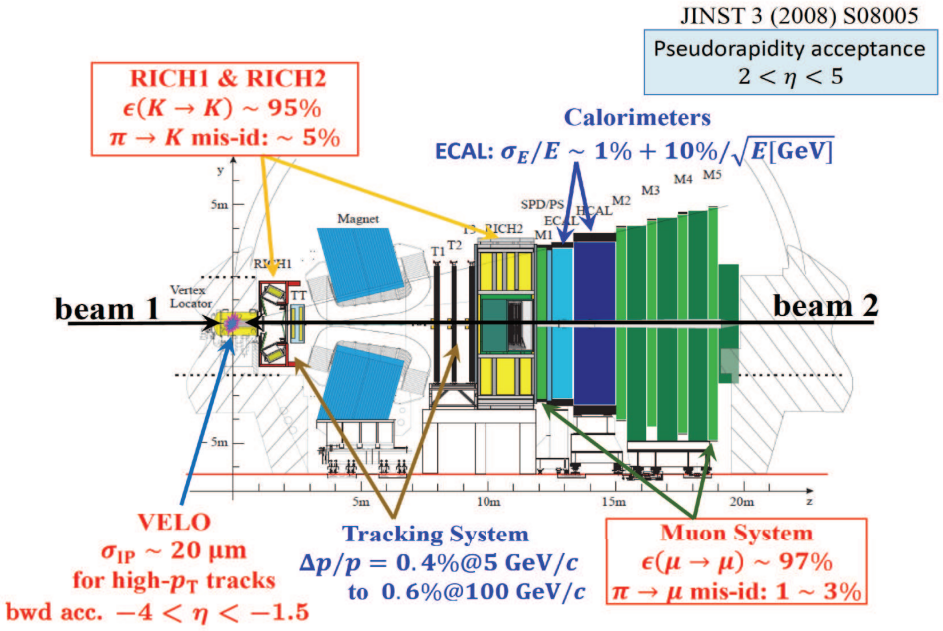

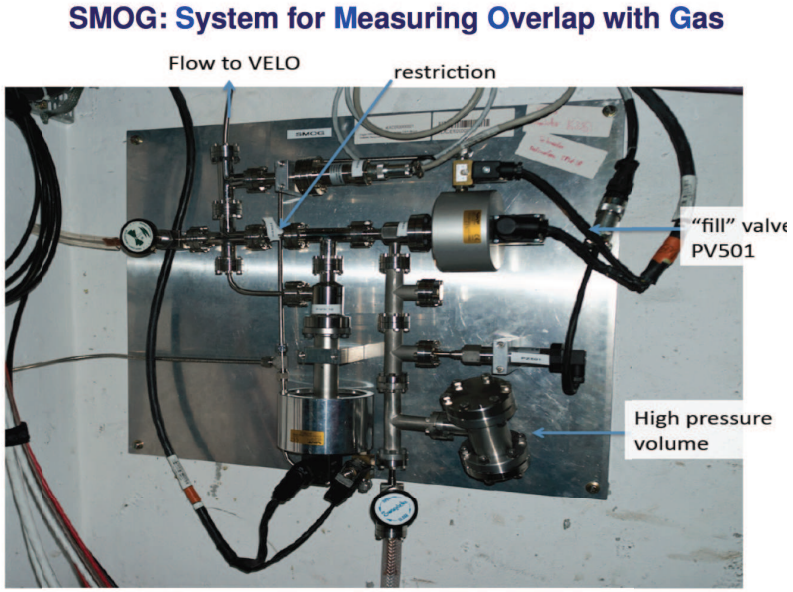

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- 1 week of PbAr (12/2015)
- Noble gases favoured
- Target unpolarised with the current SMOG system
- SMOG test : no decrease of LHC performances observed

Luminosities with a polarised internal-gas-target option

Advances in High Energy Physics
Volume 2015, Article ID 463141, 6 pages
http://dx.doi.org/10.1155/2015/463141

A Gas Target Internal to the LHC for the Study of pp Single-Spin Asymmetries and Heavy Ion Collisions

Colin Barschel,[1] Paolo Lenisa,[2] Alexander Nass,[3] and Erhard Steffens[4]

[1] *LHCb Collaboration, CERN, 1211 Geneva 23, Switzerland*
[2] *University of Ferrara and INFN, 44100 Ferrara, Italy*
[3] *Institut für Kernphysik, FZJ, 52425 Jülich, Germany*
[4] *Physics Institute, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany*

We discuss the application of an open storage cell as gas target for a proposed LHC fixed-target experiment AFTER@LHC. The target provides a high areal density at minimum gas input, which may be polarized ^{1}H, ^{2}H, or ^{3}He gas or heavy inert gases in a wide mass range. For the study of single-spin asymmetries in pp interaction, luminosities of nearly $10^{33}/\text{cm}^2$ s can be produced with existing techniques.

* $T = 300K$

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[4] *Physics Institute, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany*

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We discuss the application of an open storage cell as gas target for a proposed LHC fixed-target experiment AFTER@LHC. The target provides a high areal density at minimum gas input, which may be polarized ^{1}H, ^{2}H, or ^{3}He gas or heavy inert gases in a wide mass range. For the study of single-spin asymmetries in pp interaction, luminosities of nearly $10^{33}/\mathrm{cm}^2$ s can be produced with existing techniques.

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Luminosities with a polarised internal-gas-target option

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Figures-of-merit Comparison : $\mathrm{FoM} = P^2 \times \{f^2, \alpha^2\} \times \theta$ [E. Steffens at PSTP 2015]

$$\mathrm{FoM}^* = \phi \times \mathrm{FoM} = P^2 \times \{f^2, \alpha^2\} \times \phi \times \theta = P^2 \times f^2 \times \mathcal{L}$$

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Target and mode	Target characteristics	FoM*
NH_3 UVa-target & extr. beam	$P = 0.85; f = 0.17; \theta = 1.5 \times 10^{23}\ \mathrm{cm}^{-2}$	$1.6 \times 10^{30}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
NH_3 COMPASS & extr. beam	$P = 0.9; f = 0.176; \theta = 2.8 \times 10^{25}\ \mathrm{cm}^{-2}$	$3.5 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
'HERMES' H target* & LHC beam	$P = 0.85; \alpha = 0.95; \theta = 2.5 \times 10^{14}\ \mathrm{cm}^{-2}$	$6 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

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AFTER@LHC with an internal gas target is an extremely competitive option !

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Conclusion

- Our multi-faceted FCPPL consortium is doing very well !
- Many franco-chinese exchanges on various topics

[F. Scarpa will go to a school in CCNU in May]

- Regular publications
- Many prospects both for the theory and the experimental side

[I have not mentioned TMD studies at NLO for instance with J.X. Wang]

- We are very excited by the recent technical advances for AFTER@LHC

[I have not mentioned the test of bent crystals in the LHC beampipe]

- The door is being opened for

  prospective studies for ALICE in the fixed target mode
- Hopefully, at the next FCPPL meeting,

  the EoI will be submitted to the LHCC

Part I

Backup

Why a fixed-target experiment at the LHC ?

- Advance our understanding of the large-x gluon, antiquark and heavy-quark content in the nucleon & nucleus

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  - Very large PDF uncertainties for $x \gtrsim 0.5$.

    [could be crucial to characterise possible BSM discoveries]
  - Proton charm content important to high-energy neutrino & cosmic-rays physics
  - EMC effect is an open problem; studying a possible gluon EMC effect is essential
  - Relevance of nuclear PDF to understand the initial state of heavy-ion collisions
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  - Explore the longitudinal expansion of QGP formation with new hard probes
  - Test the factorisation of cold nuclear effects from $p + A$ to $A + B$ collisions
  - Test the formation of azimuthal asymmetries: hydrodynamics vs. initial-state radiation

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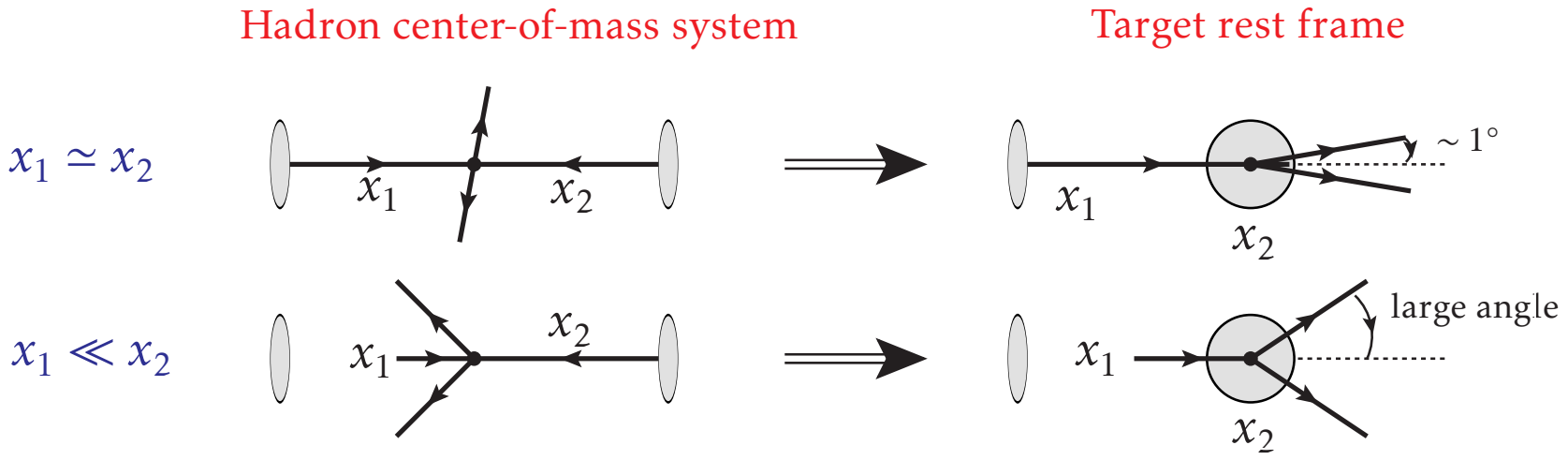

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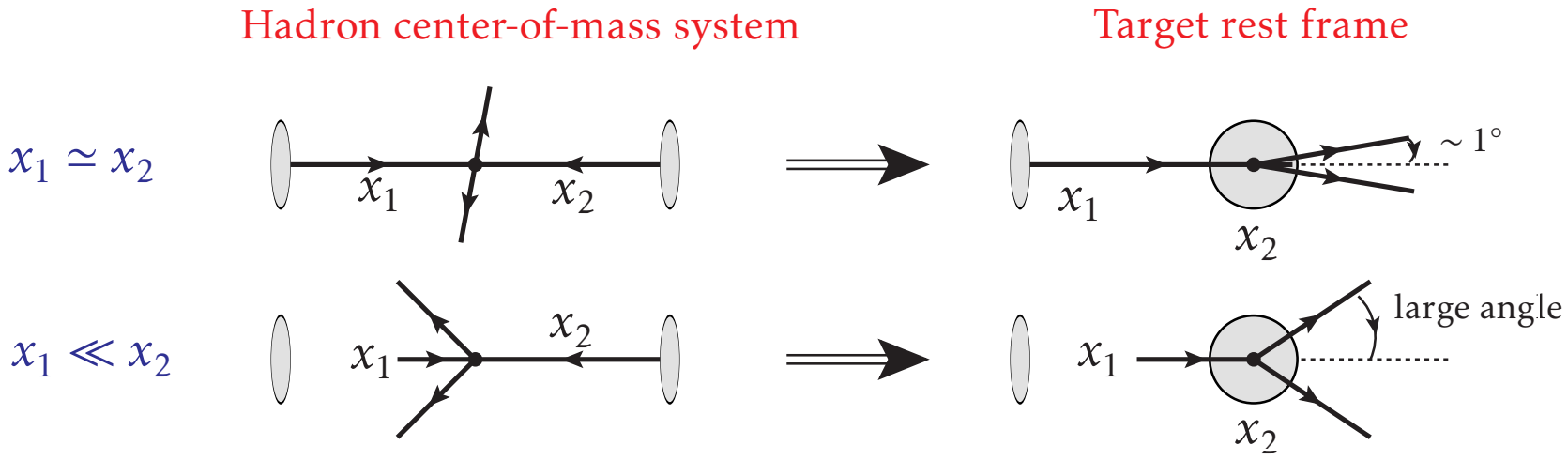

backward physics = large-x_2 physics