# AFTER @ LHC

## The Spin Physics Program

**Daniel Kikoła, Warsaw University of Technology**

**AFTER@LHC Study group:**
**http://after.in2p3.fr/after/index.php/Current_author_list**

# Outline

- Why a fixed-target experiment at the LHC?
- Physics motivation
- Fixed-target collisions at the LHC
- Selected spin physics cases
- Summary & status

# Why a fixed-target experiment at the LHC?

- High luminosities
- Access to high Feynman $x_F$ domain ($|x_F| = |p_z|/p_{z\,max} \rightarrow 1$)
- Variety of atomic mass of the target
- Polarization of the target → **spin physics at the LHC**

# Why a fixed-target experiment at the LHC?

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- Variety of atomic mass of the target
- Polarization of the target → **spin physics at the LHC**

Can be realised at CERN in a parasitic mode with the most energetic beams ever!

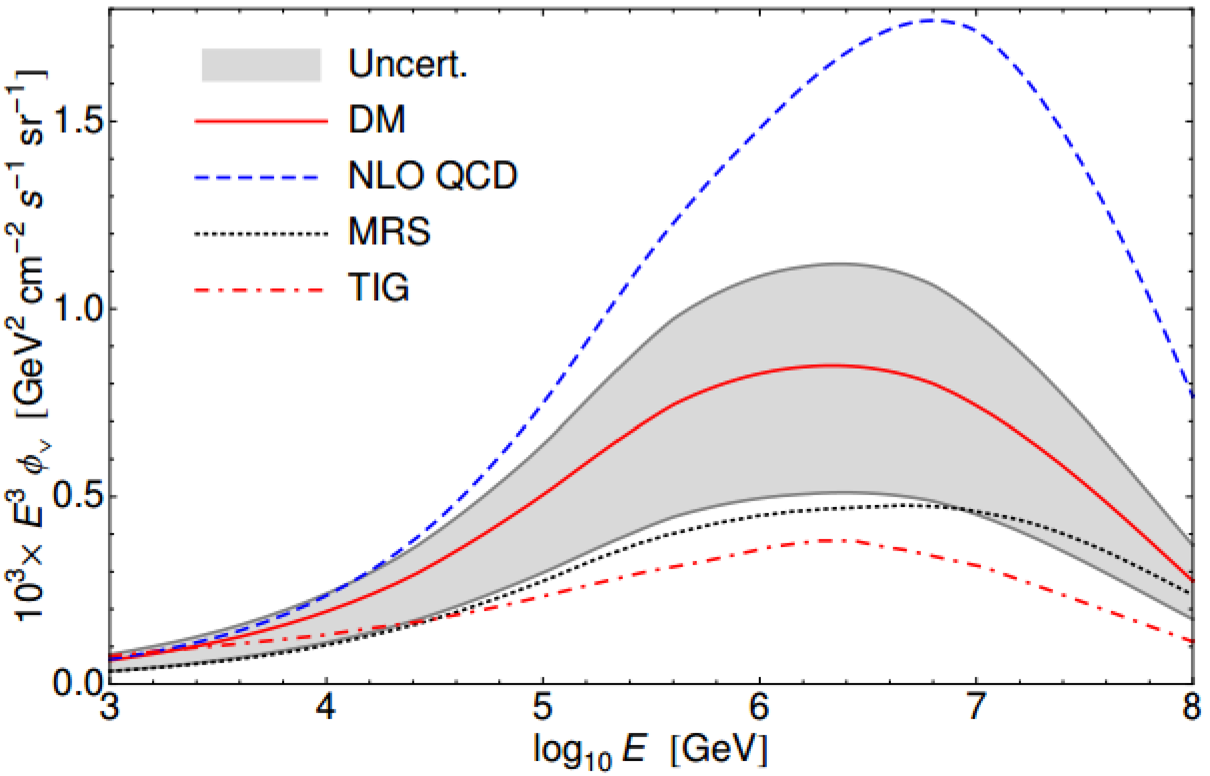
# Physics program

# Broad physics program

- High-x gluon, antiquark and heavy-quark content in the nucleon & nucleus

Example:
Reducing unc. in high-energy neutrino & cosmic-rays physics

**Energy spectrum of neutrino flux**




Phys.Rev.D78:043005,2008

# Physics program

- Heavy-ion collisions

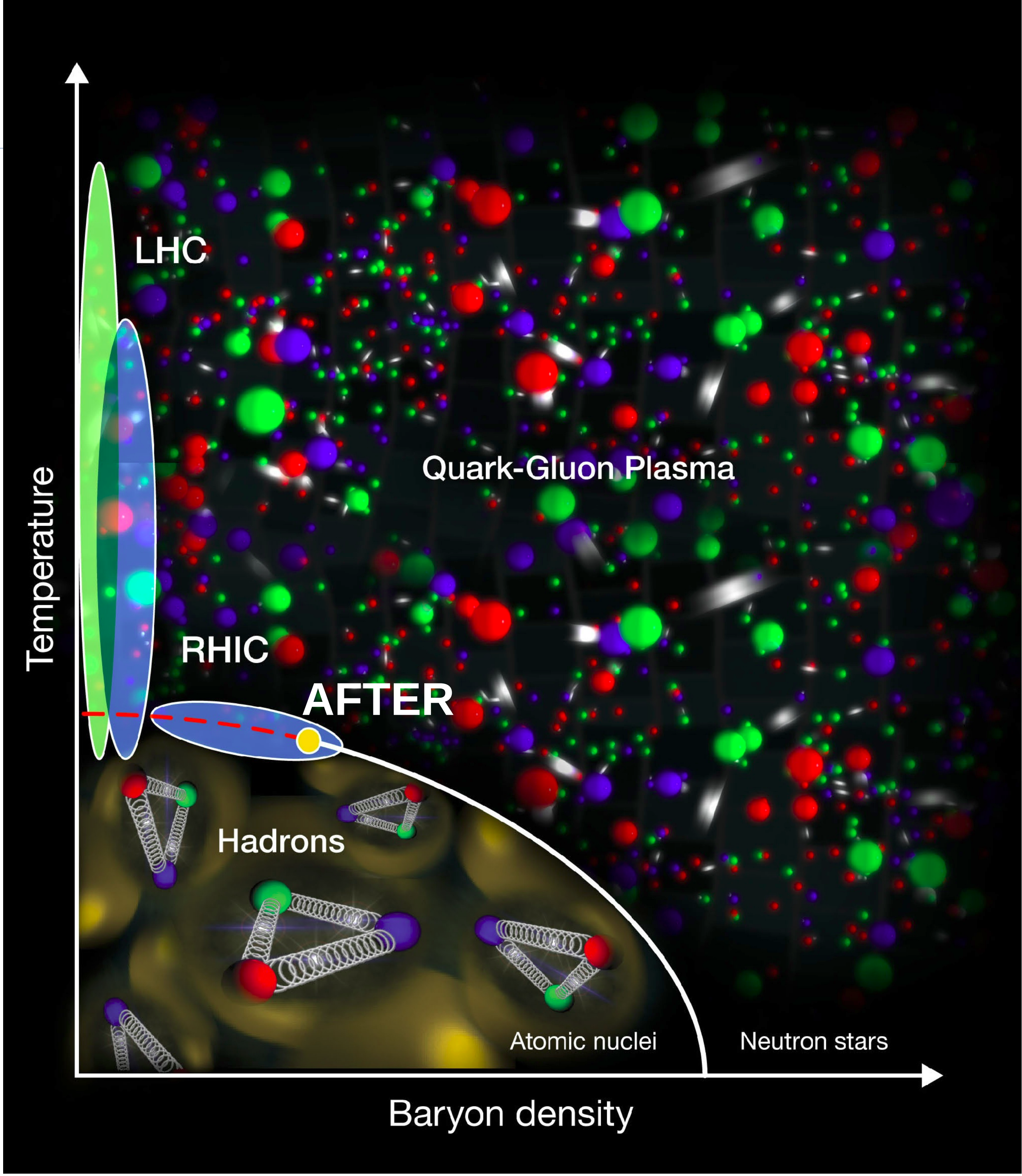



Figure adopted from: https://www.bnl.gov/newsroom/news.php?a=24281

# Physics program

- High-x gluon, antiquark and heavy-quark content in the nucleon & nucleus

- Heavy-ion collisions
  - properties of partonic matter

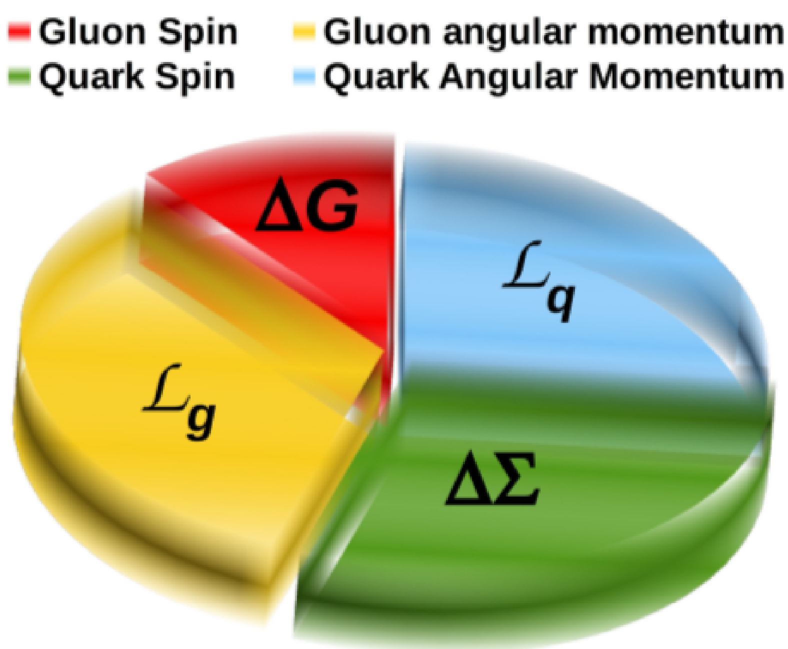
- **Transverse dynamics and spin of gluons inside (un)polarised nucleons**

# The Spin Physics Program

## 3D mapping of the parton momentum:

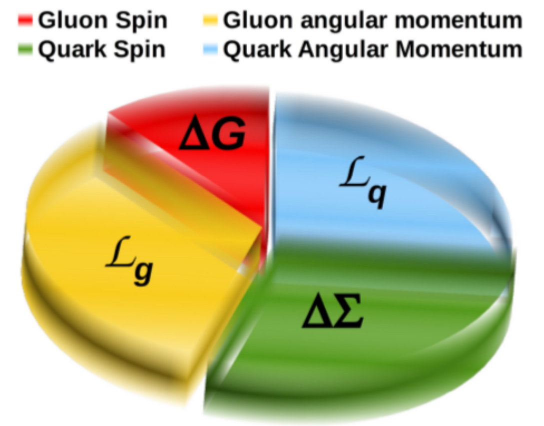
- Missing contribution to the proton spin: Gluon and Quark Orbital Angular Momentum $L_q$ and $L_g$

**→ p+p$^{\uparrow}$ → (indirect) access to quark $L_q$, gluon $L_g$ and gluon TMDs**



# The Spin Physics Program

## 3D mapping of the parton momentum:

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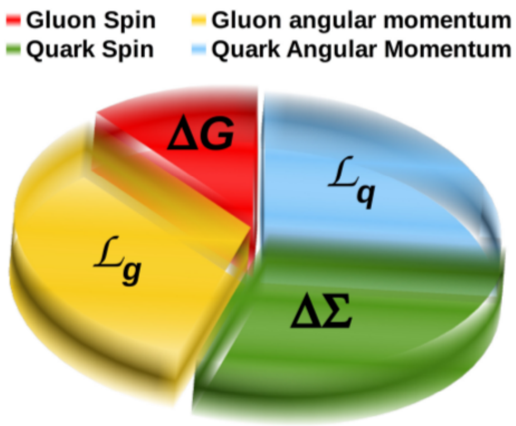
- Test of the QCD factorization framework

# The Spin Physics Program

## 3D mapping of the parton momentum:

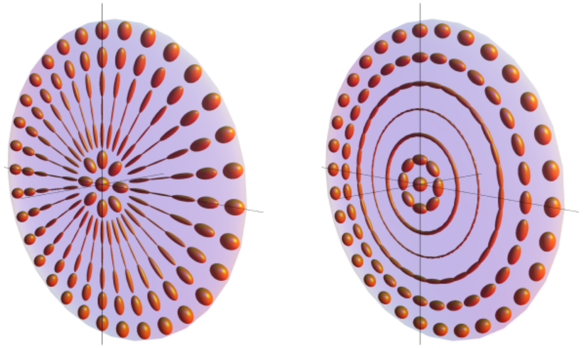



- Missing contribution to the proton spin: Gluon and Quark Orbital Angular Momentum $L_q$ and $L_g$

  **→ p+p$^{\uparrow}$ → (indirect) access to quark $L_q$, gluon $L_g$ and gluon TMDs**

- Test of the QCD factorization framework

- Determination of the linearly polarized gluons in unpolarized protons

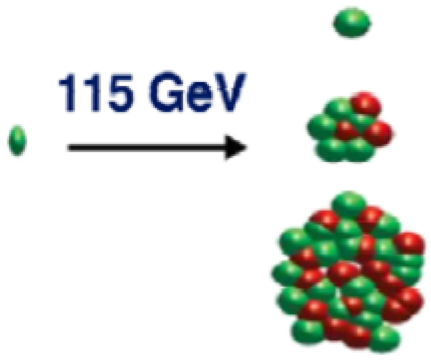


Phys. Rev. Lett. 112, 212001

# Fixed-target collisions at LHC

# Kinematics

- p+p or p+A with a 7 TeV p on a fixed target

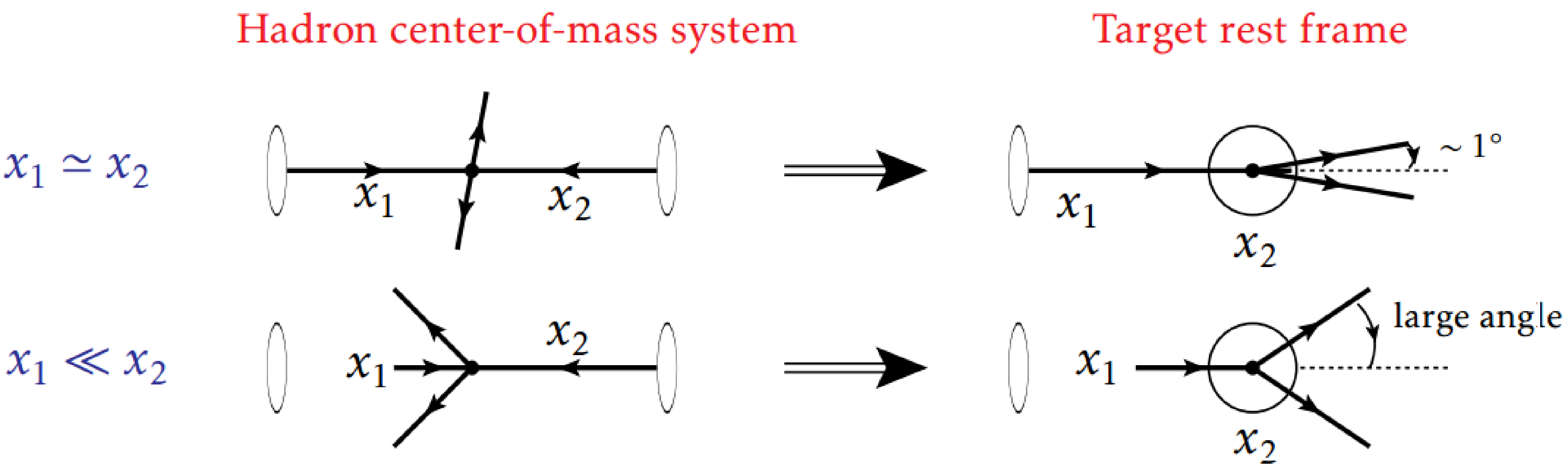



$$\sqrt{s}=\sqrt{2m_N E_p}\approx 115\,GeV$$

$$y_{CMS}=0 \rightarrow y_{Lab}=4.8$$

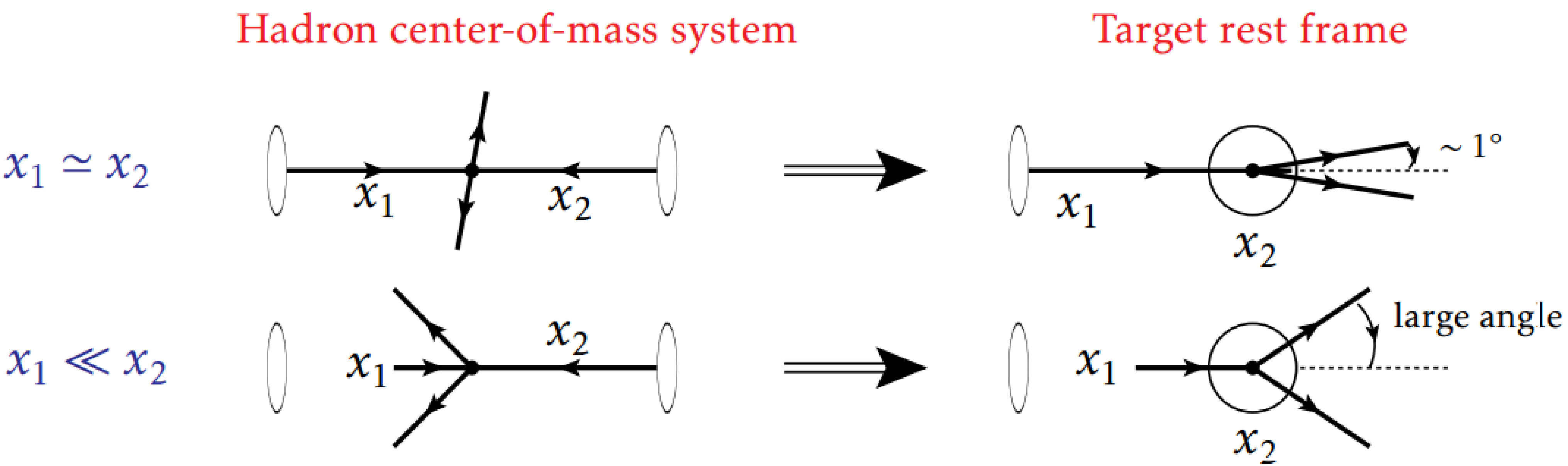
# Access to backward physics

## Boost effect:



# Access to backward physics

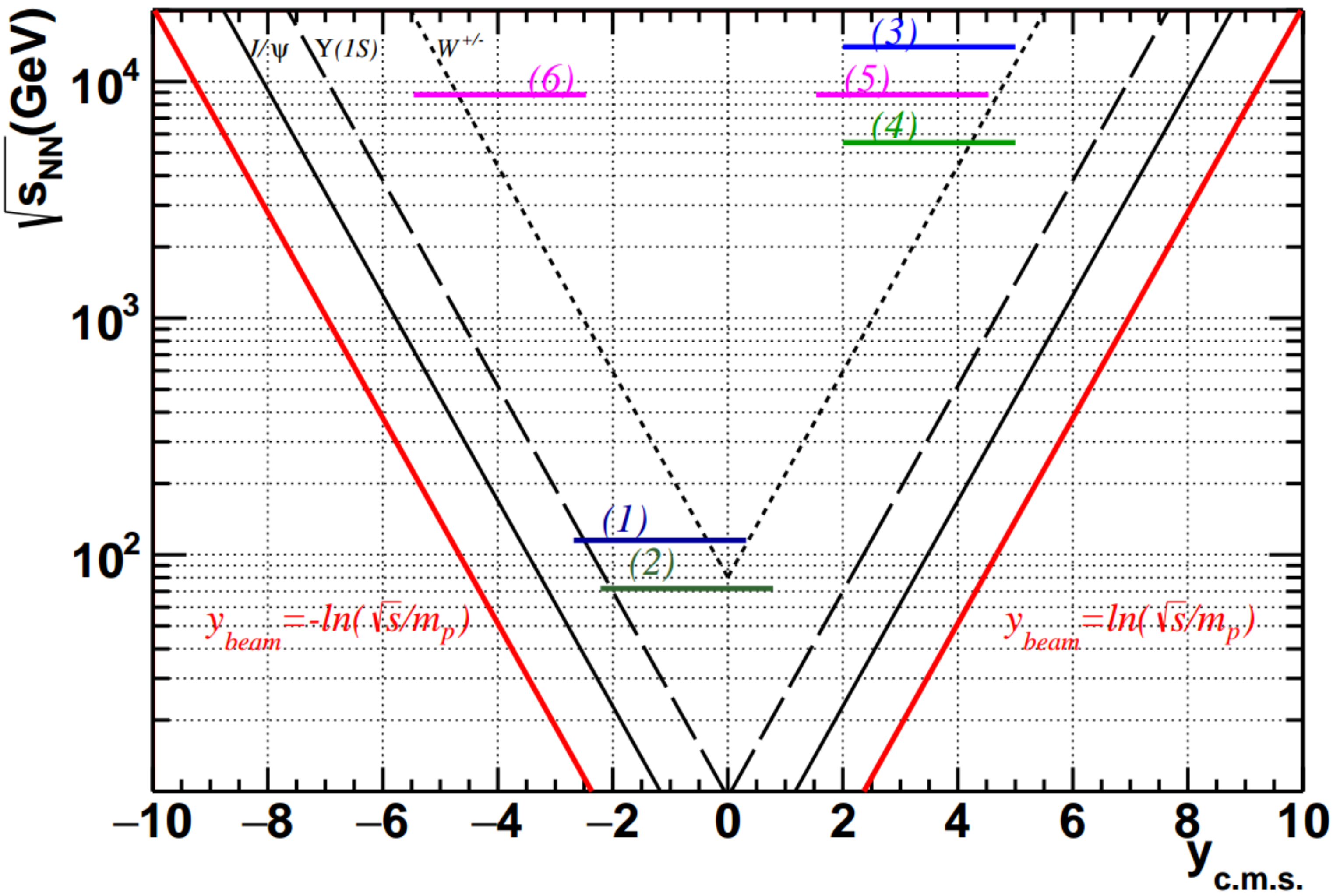
## Boost effect:




backward physics = large-$x_2$ physics

( $x_F < 0 \rightarrow$ large $x^{\uparrow}$ )

# Acceptance for LHCb-type detector




$2 < \eta^{lab} < 5$

(1) fixed target, $\sqrt{s_{NN}}$ = 115 GeV; (2) fixed target, $\sqrt{s_{NN}}$ = 72 GeV;
(3) collider mode, $\sqrt{s}$ = 14 TeV; (4) collider mode, $\sqrt{s_{NN}}$ = 5.5 TeV,
(5),(6) $\sqrt{s_{NN}}$ = 8.8 TeV

# Fixed-target modes at LHC beams

- Internal target + existing detector
  - gas target (unpolarized/polarized) and full LHC beam
  - beam splitting by bent-crystal + internal (solid, pol.?) target

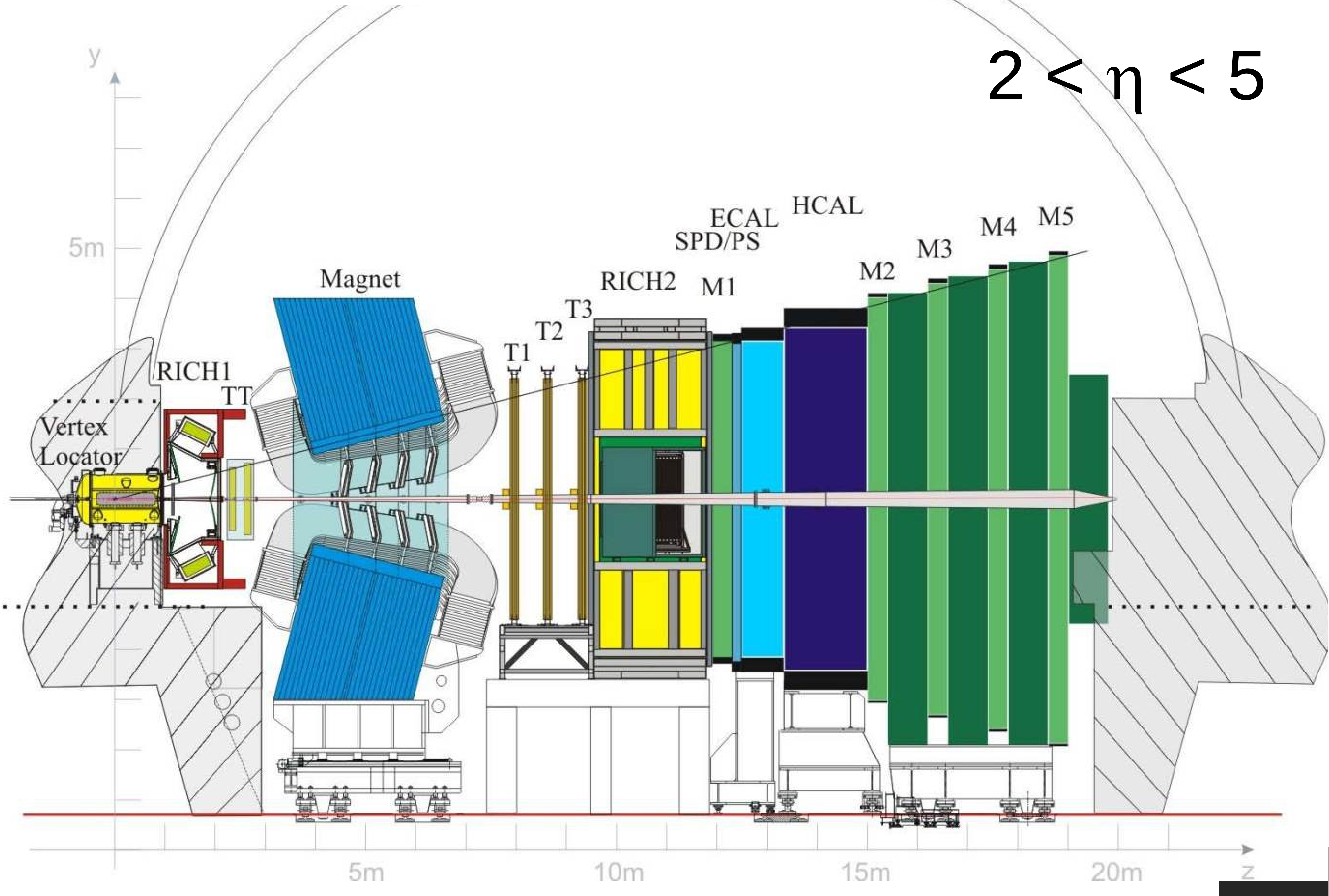
- Beam extraction by bent-crystal
  - new beam line + new experiment

# Internal gas target

- Can be installed in existing LHC caverns or tunnel, and coupled to existing experiments
- Validated by **LHCb** via a luminosity monitor (**SMOG**)
- Takes the full LHC beam without loss in lifetime

**SMOG-LHCb:**
System for Measuring Overlap with Gas

$$2 < \eta < 5$$

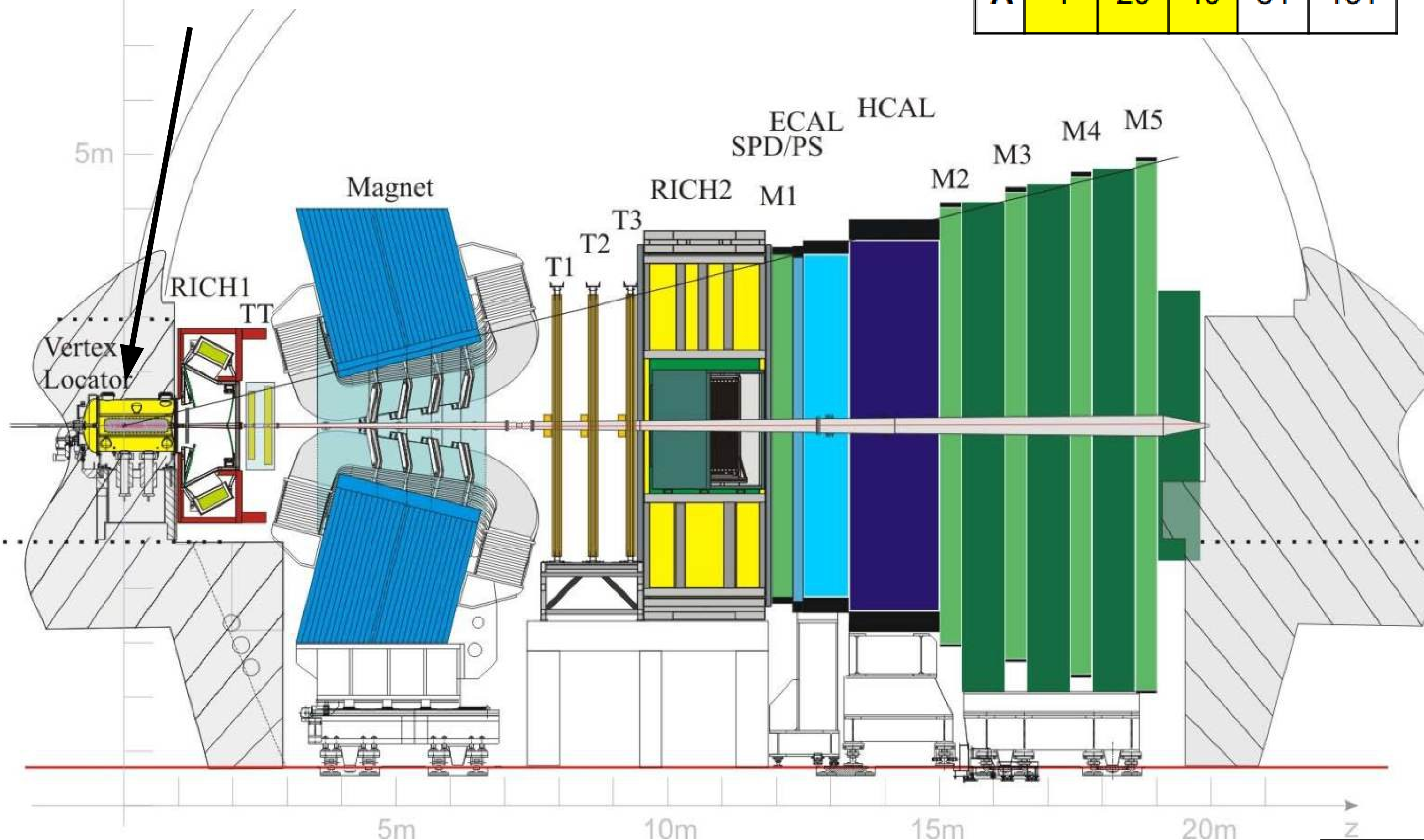


# SMOG-LHCb:

Gas injected into
into beam vacuum

Preferred target Gas

| | He | Ne | Ar | Kr | Xe |
|---|---|---|---|---|---|
| A | 4 | 20 | 40 | 84 | 131 |



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**Gas injected into into beam vacuum**

Preferred target Gas

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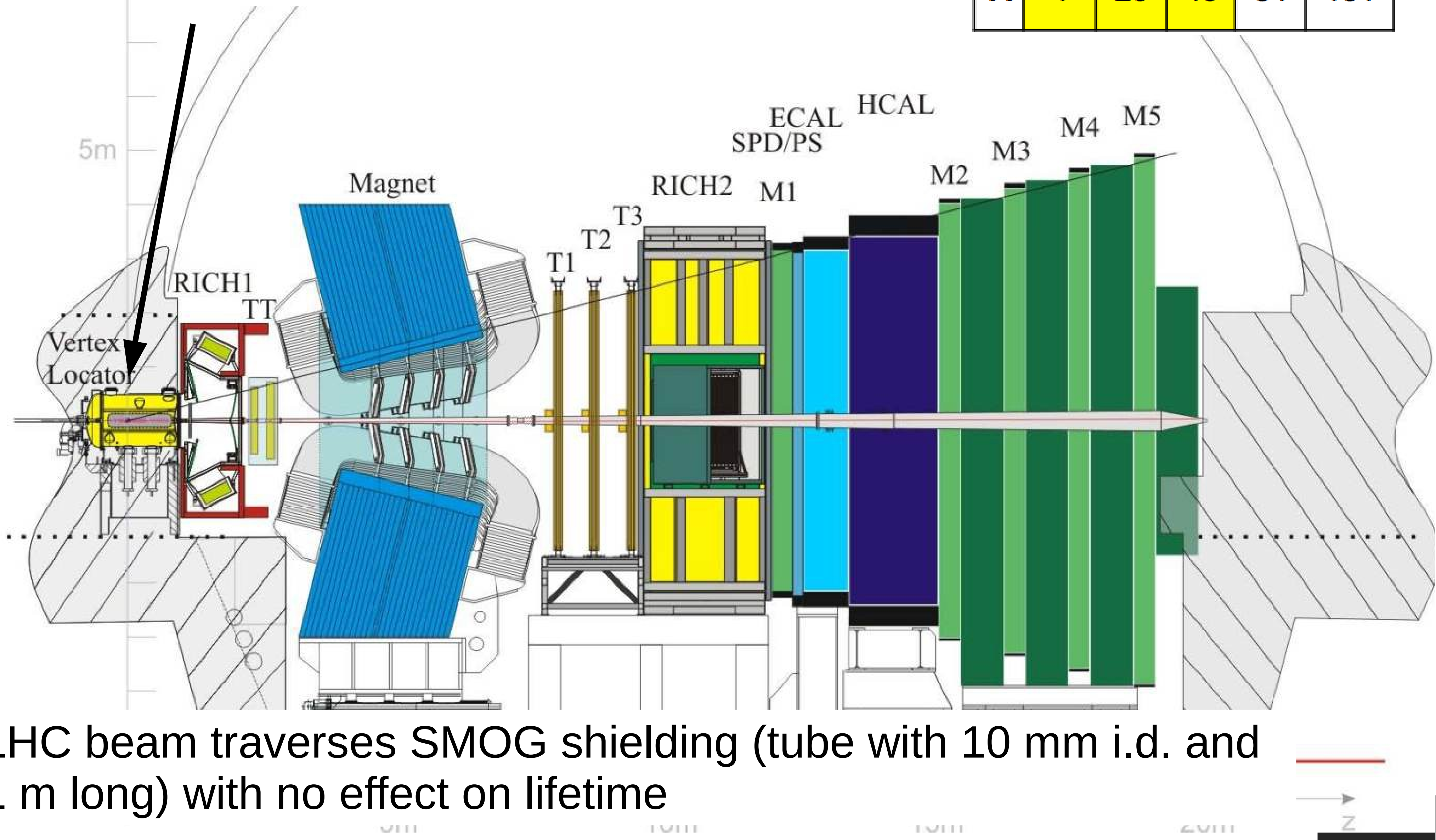
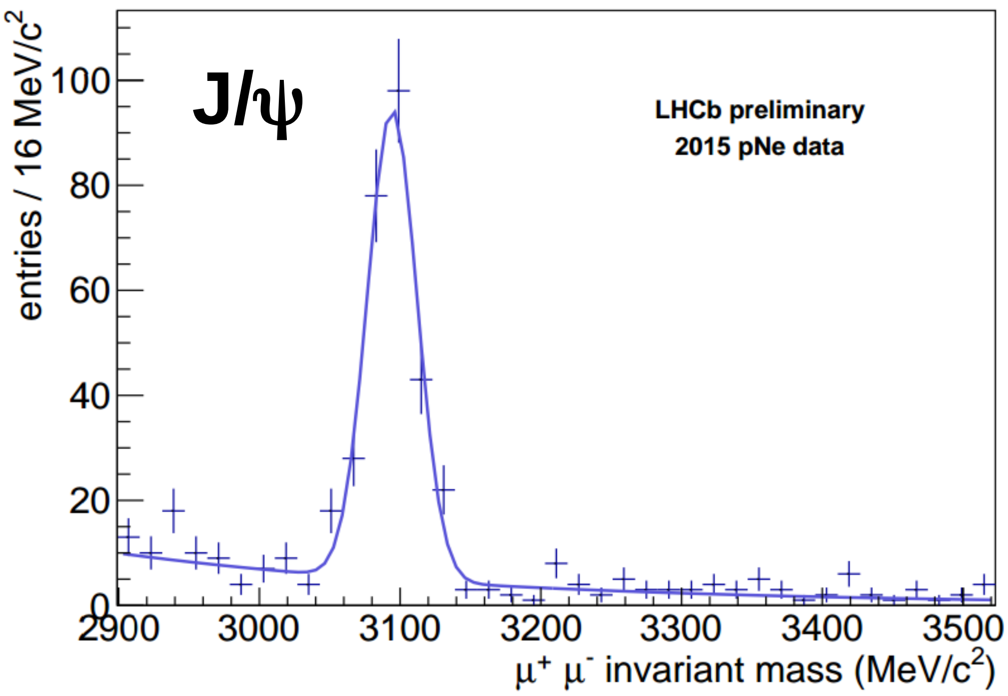
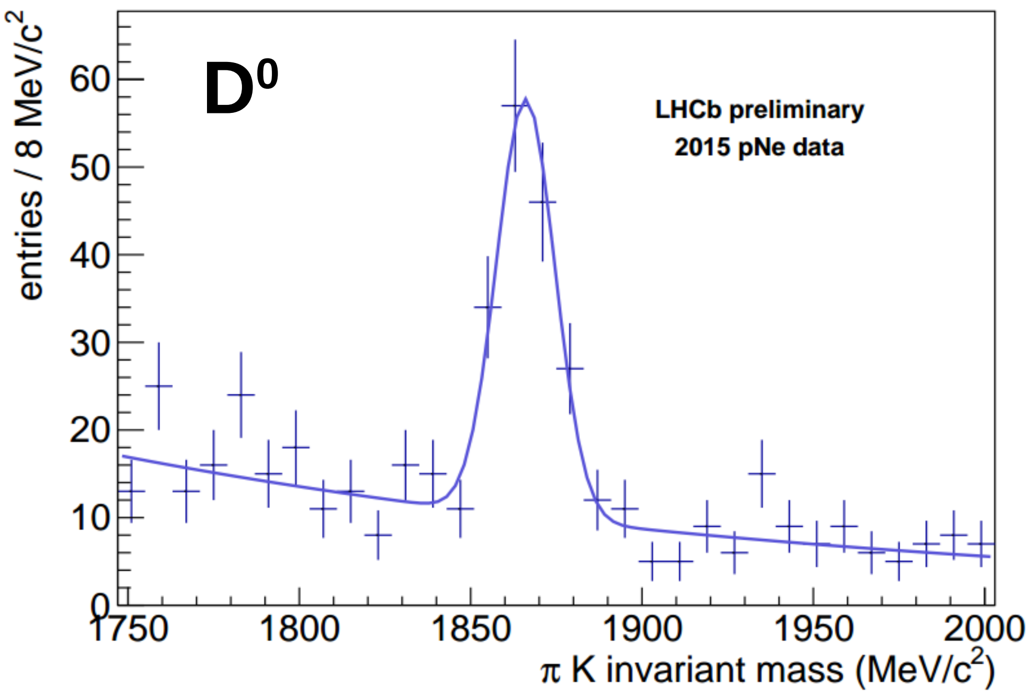



LHC beam traverses SMOG shielding (tube with 10 mm i.d. and 1 m long) with no effect on lifetime

# SMOG-LHCb data



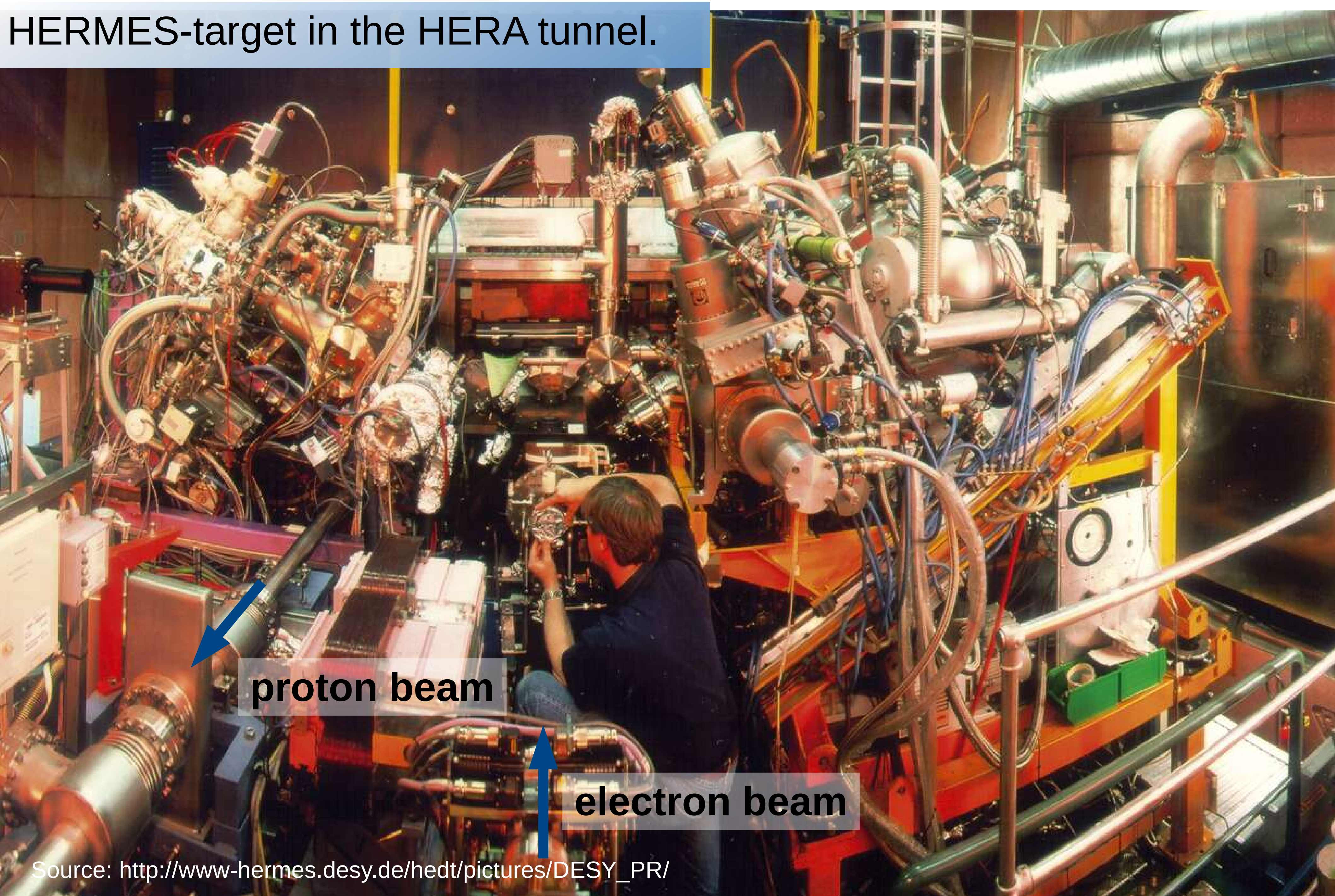

Successful p+A and A+A data taking

Good resolution, low background

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

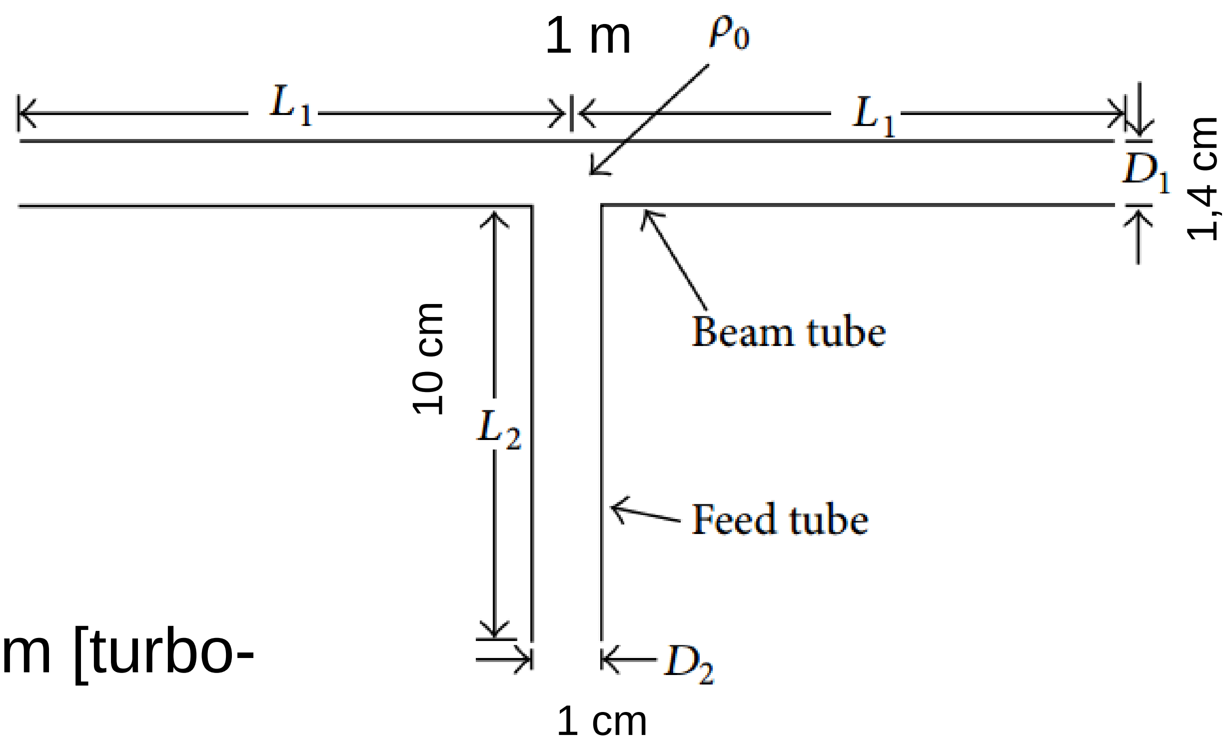
# Polarized target: HERMES-type system

HERMES-target in the HERA tunnel.




Source: http://www-hermes.desy.de/hedt/pictures/DESY_PR/

# Polarized target: HERMES-type system




- Dedicated pumping system [turbo-molecular pumps]
- Polarised H and D injected ballistically in open-end storage cell with high polarisation ~80%
- Polarised $^3$He or unpolarised heavy gas (Kr, Xe) can also be injected

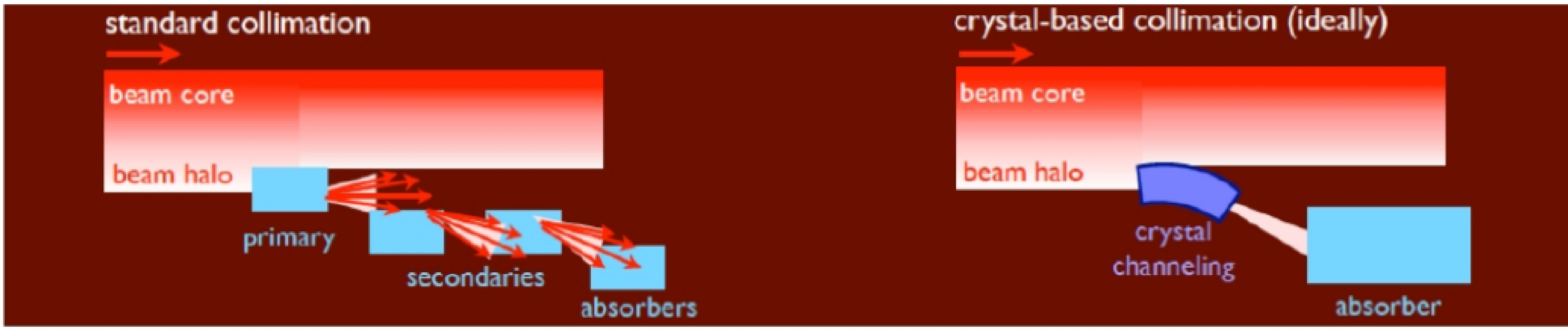
Adv. High Energy Phys. 2015 (2015) 463141

E. Steffens, PoS (PSTP2015) 019

**See talk by P. Lenisa for details**

# Beam splitting by bent-crystal

## Motivation: beam collimation




Standard collimation today → Crystal-based collimation
- UA9 (@SPS)
- LUA9 (@LHC)

→ To beam extraction
- CRYSBEAM (@SPS then LHC)
- AFTER@LHC

*W. Scandale et al., JINST 6 T10002 (2011)*

→ Deflecting the beam halo at 7σ distance to the beam
→ Reduces the LHC beam loss
→ Beam extraction: civil engineering required, new facility with 7 TeV proton beam
→ Beam splitting: intermediate option, might be used with existing experiment

Expected operation parameters at AFTER:

→ Luminosity $\int \mathscr{L}$ **= 10 fb$^{-1}$ /year**

→ Target polarization **P** ~ **80%**

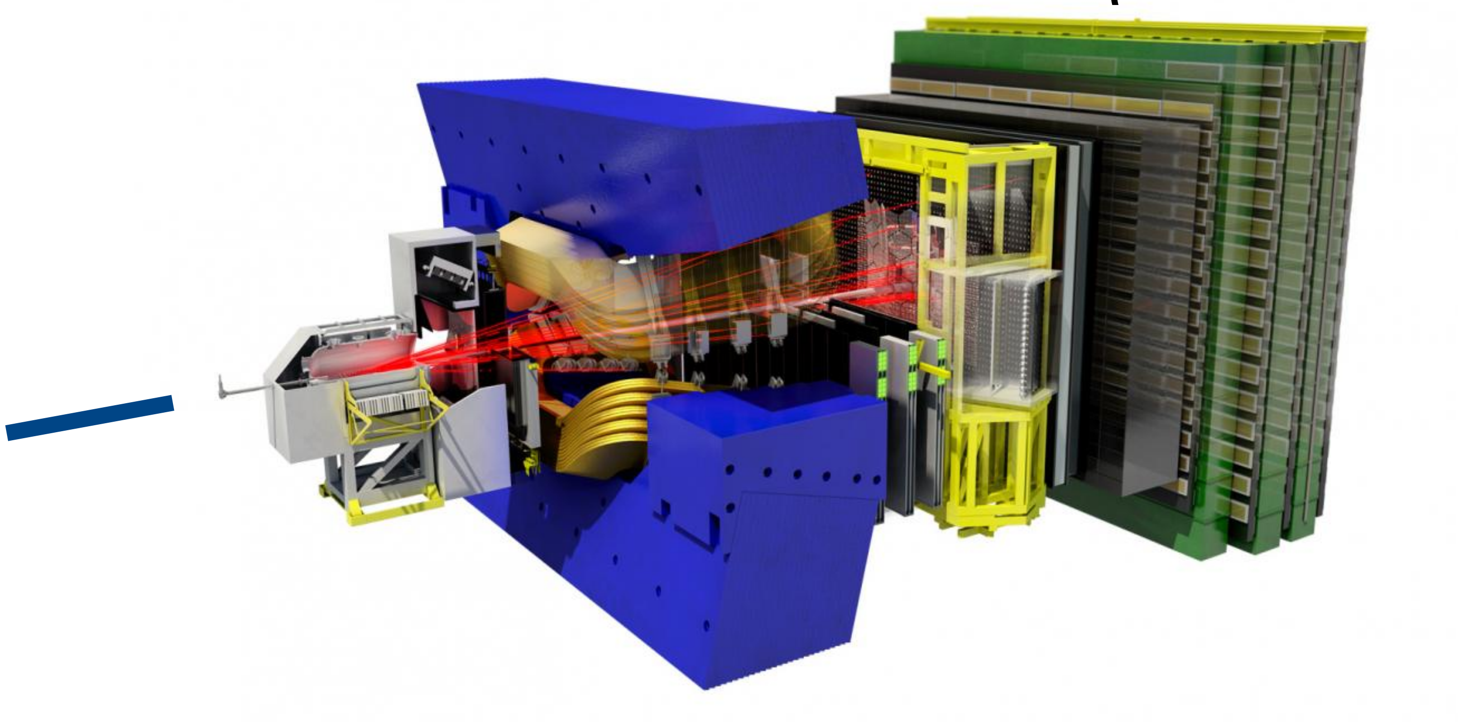
Avg. polarization P = 80% assumed based on the HERMES target performance

# Sensitivity studies - assumptions

$\int \mathscr{L} = 10 \text{ fb}^{-1}$ /year

P = 60%

2 < η < 5



HERMES-type
polarized target

+

LHCb – like acceptance
and performance

microvertexing, particle ID, μ ID,
electromagnetic and hadonic cal.

# Spin physics cases at AFTER@LHC

# Orbital angular momentum of quarks and gluons

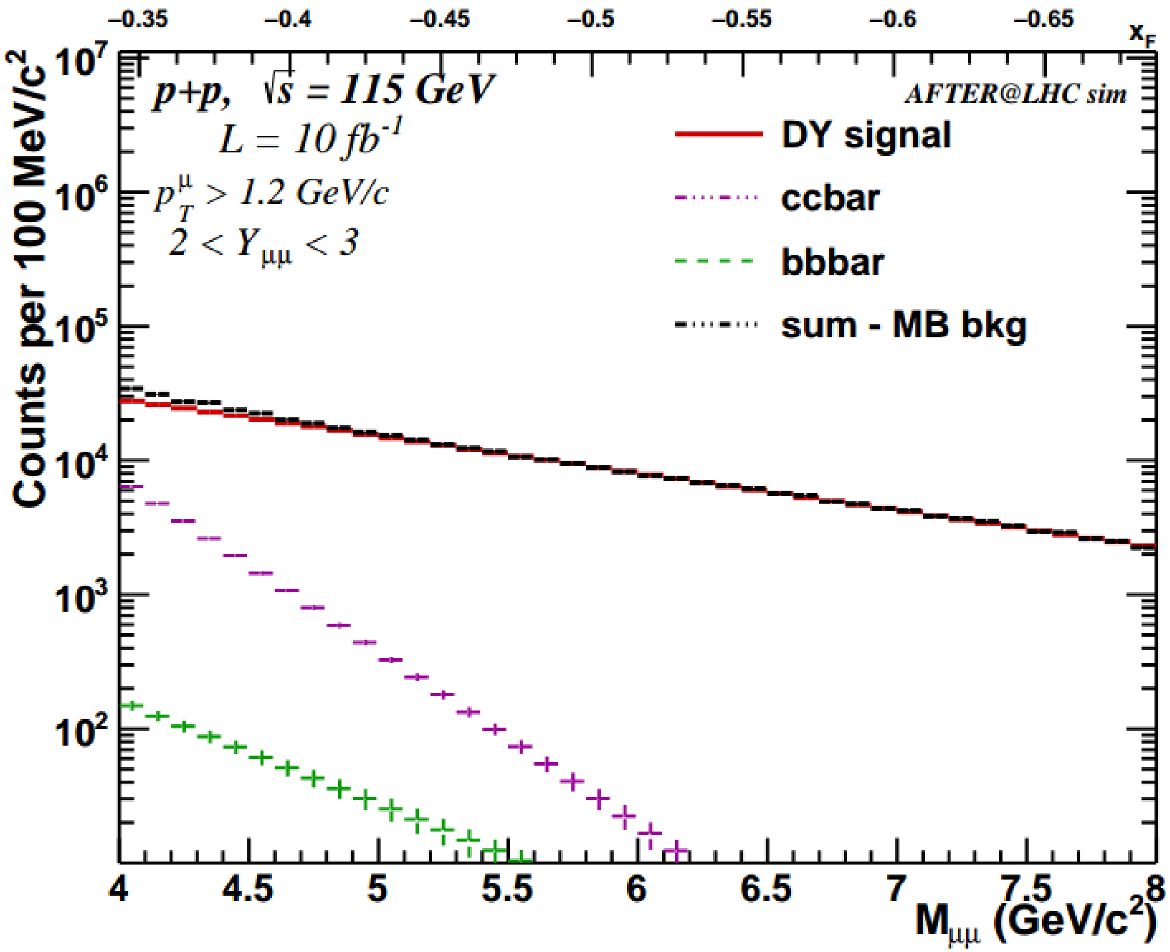
- non-zero quark/gluon Sivers function → non-zero quark/gluon OAM

- Drell-Yan $A_N$ → access to $f_{1T}^{\perp q}(x, \vec{k}_\perp^2)$

- Gluon Sivers effect
  - essentially unconstrained
  - access via $A_N$ of open charm & quarkonia, $J/\psi$-$J/\psi$, $J/\psi+\gamma$

# Drell-Yan in AFTER

- Drell-Yan in AFTER
  - large yields



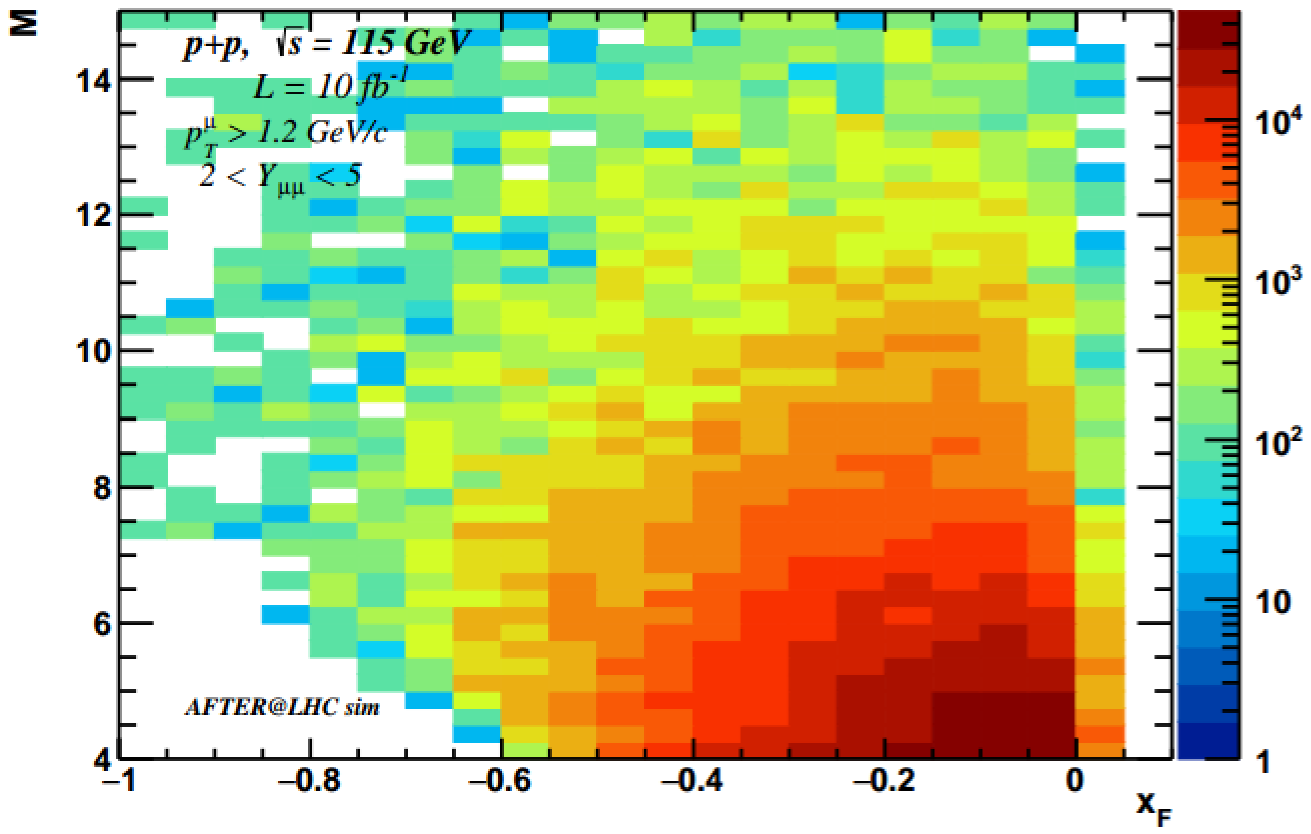

DY studied also for

**3 < yμμ < 4** and

**4 < yμμ < 5**

# Drell-Yan in AFTER

- Drell-Yan in AFTER
  - large yields & broad kinematic reach ($10^{-2} < x^{\uparrow} < 0.9$)



# Drell-Yan in AFTER

- Drell-Yan in AFTER
  - large yields & broad $x^{\uparrow}$ reach: $10^{-2} < x^{\uparrow} < 0.9$

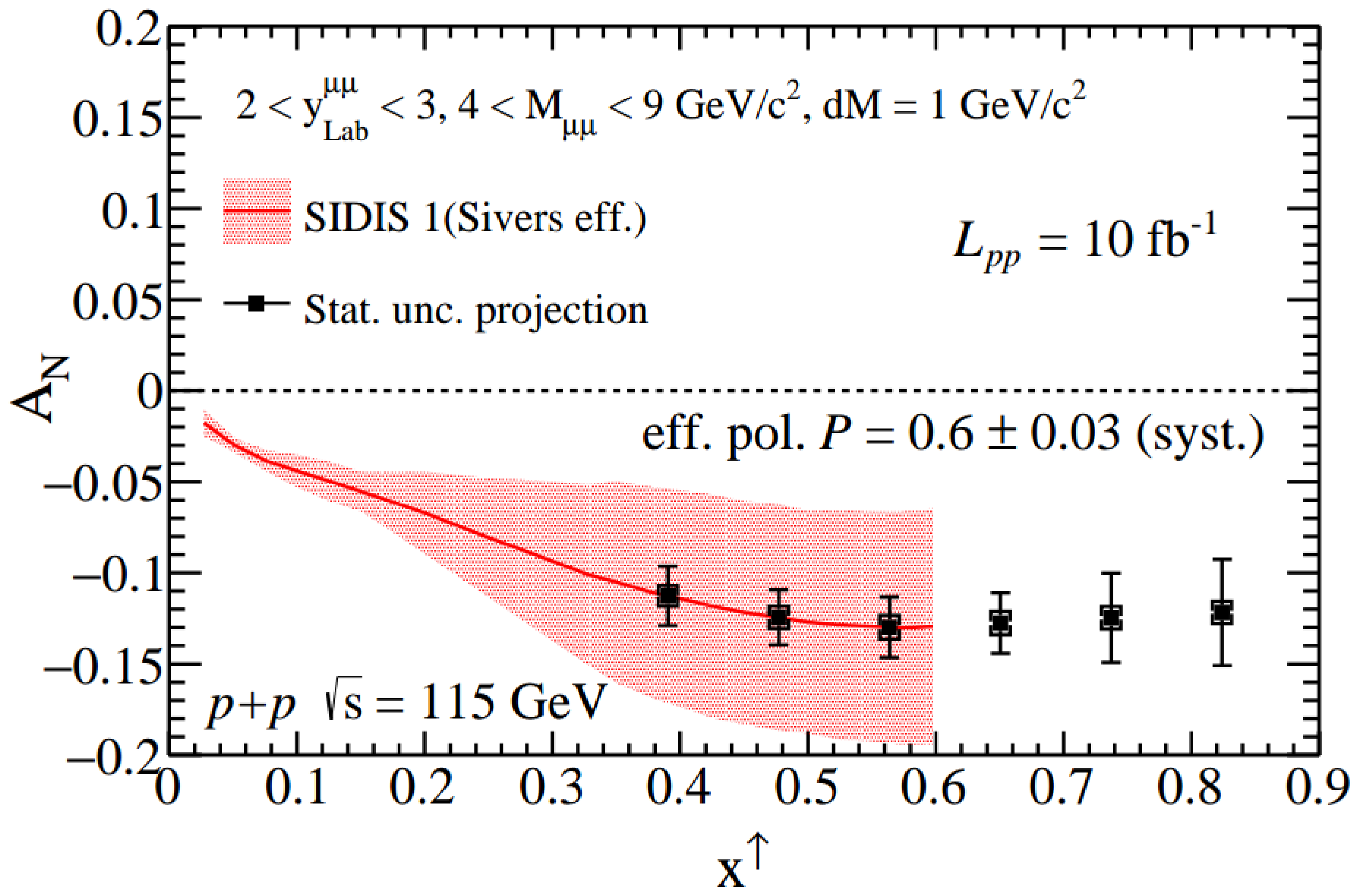
- High $x^{\uparrow} \rightarrow$ largest $k_T$ – spin correlation, largest asymmetry expected

# Drell-Yan $A_N$ in AFTER

Precision study of the quark Sivers function with Drell-Yan

$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

P – effective target polarization



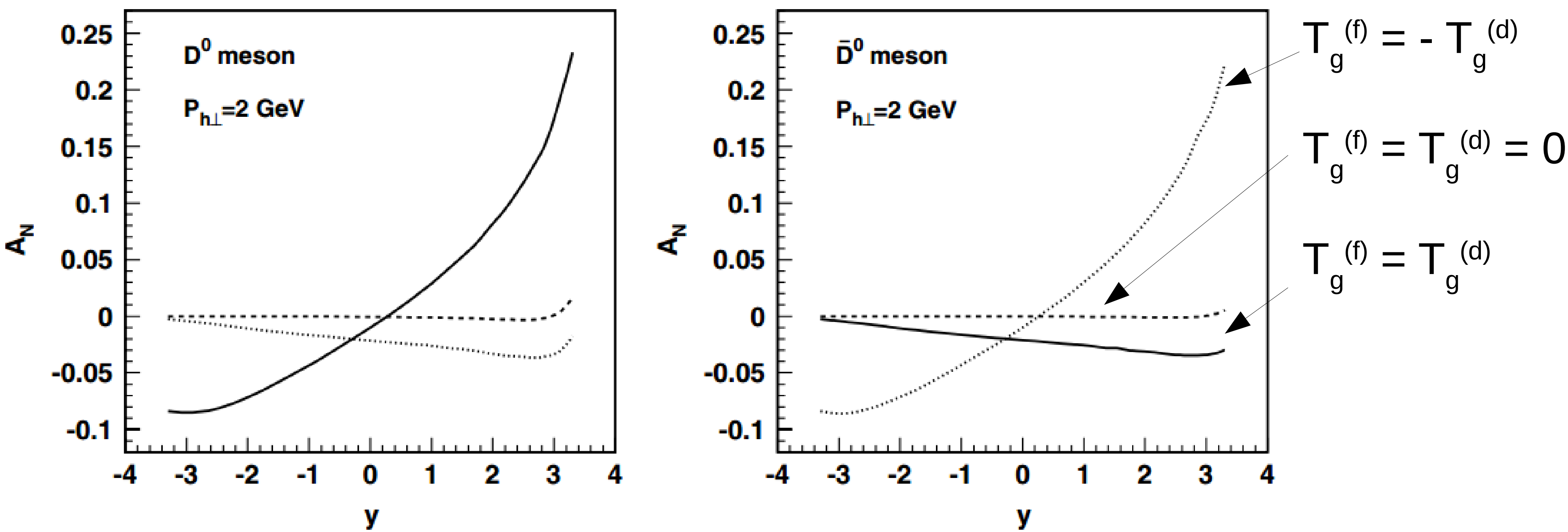

STSA predictions for the AFTER@LHC kinematics:

- M. Anselmino, U. D'Alesio, and S. Melis. Adv. Hi. En. Phys. (2015) 475040.
- K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak. Adv. Hi. En. Phys. (2015) 257934.
- T. Liu, B.Q. Ma. Eur. Phys. J. C72 (2012) 2037

# Open charm $A_N$

- Access to the tri-gluon correlation and (indirectly) the gluon Sivers effect ($\rightarrow L_g$) [First hint by COMPASS that $L_g \neq 0$, J. Phys.: Conf. Ser. 678 012055]
- Unique study: $A_N$ of $D^0$ vs $\bar{D}^0 \rightarrow$ access to C-odd correlators

PRD 78, 114013 (2008)

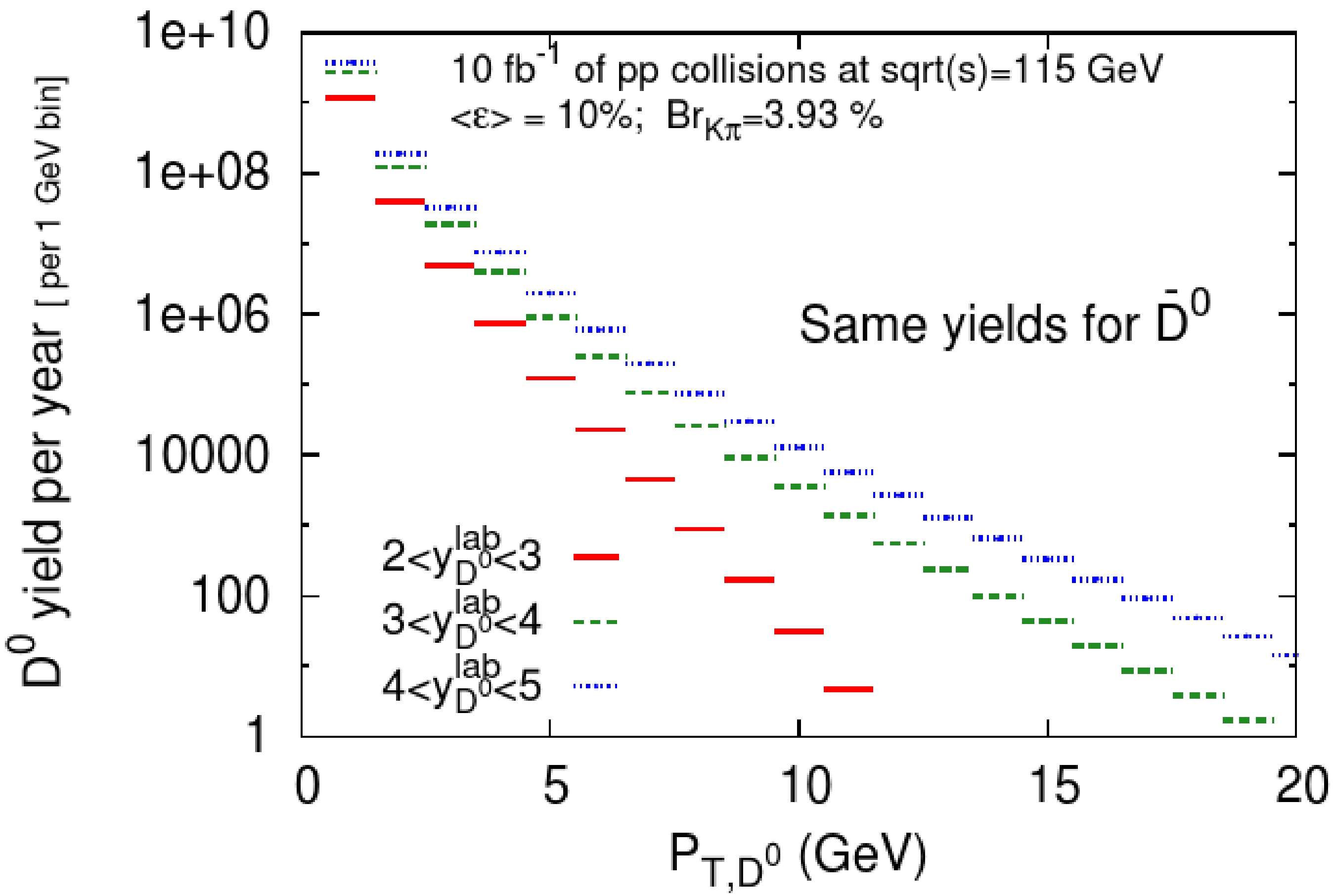



PRD 78, 114013 (2008)

$T_g^{(f)}$, $T_g^{(d)}$ – tri-gluon corr. functions

# Open Heavy Flavour simulations

$D^0 \to K^- \pi^+$

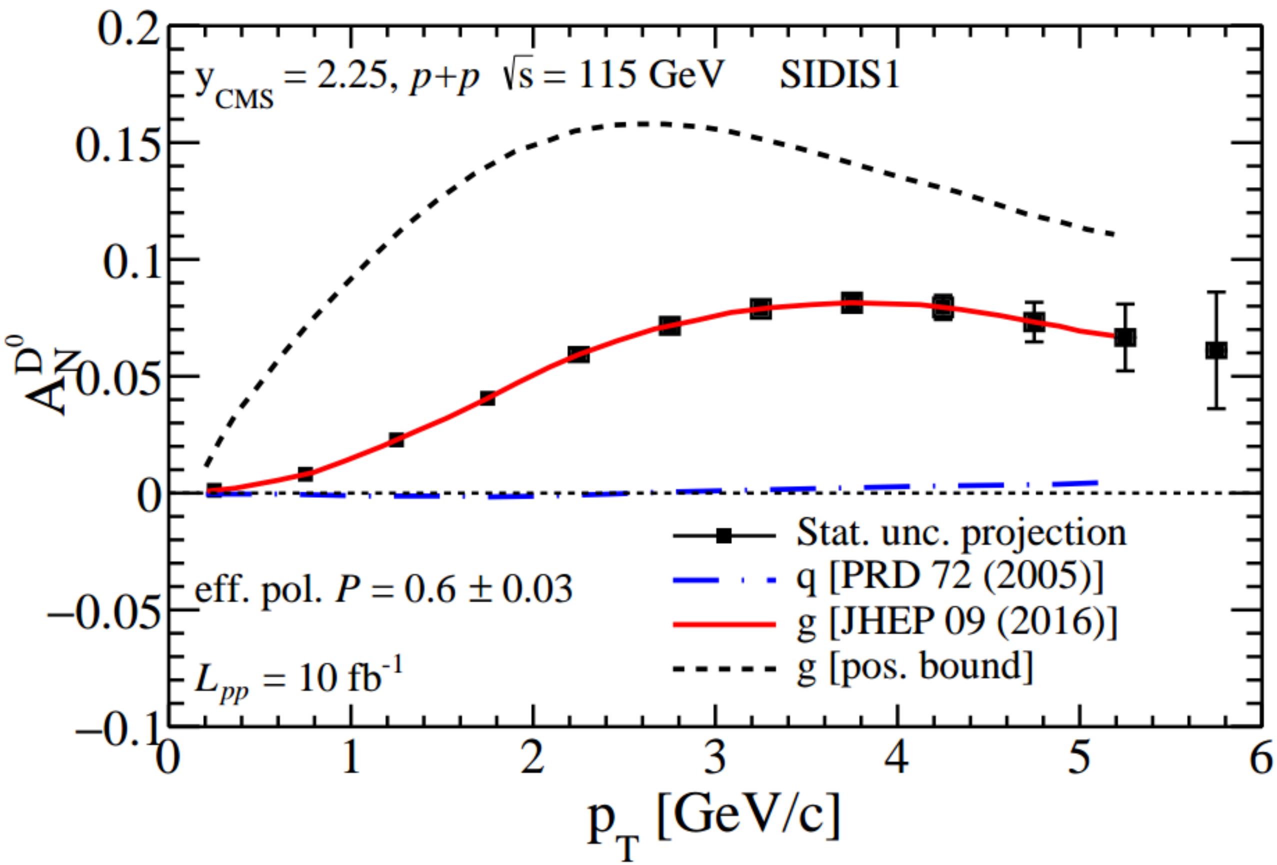



- Huge yields
- Charm measured down to 0 $p_T$
- Constraint the intrinsic charm in proton

# Sensitivity predictions: Open charm $A_N$

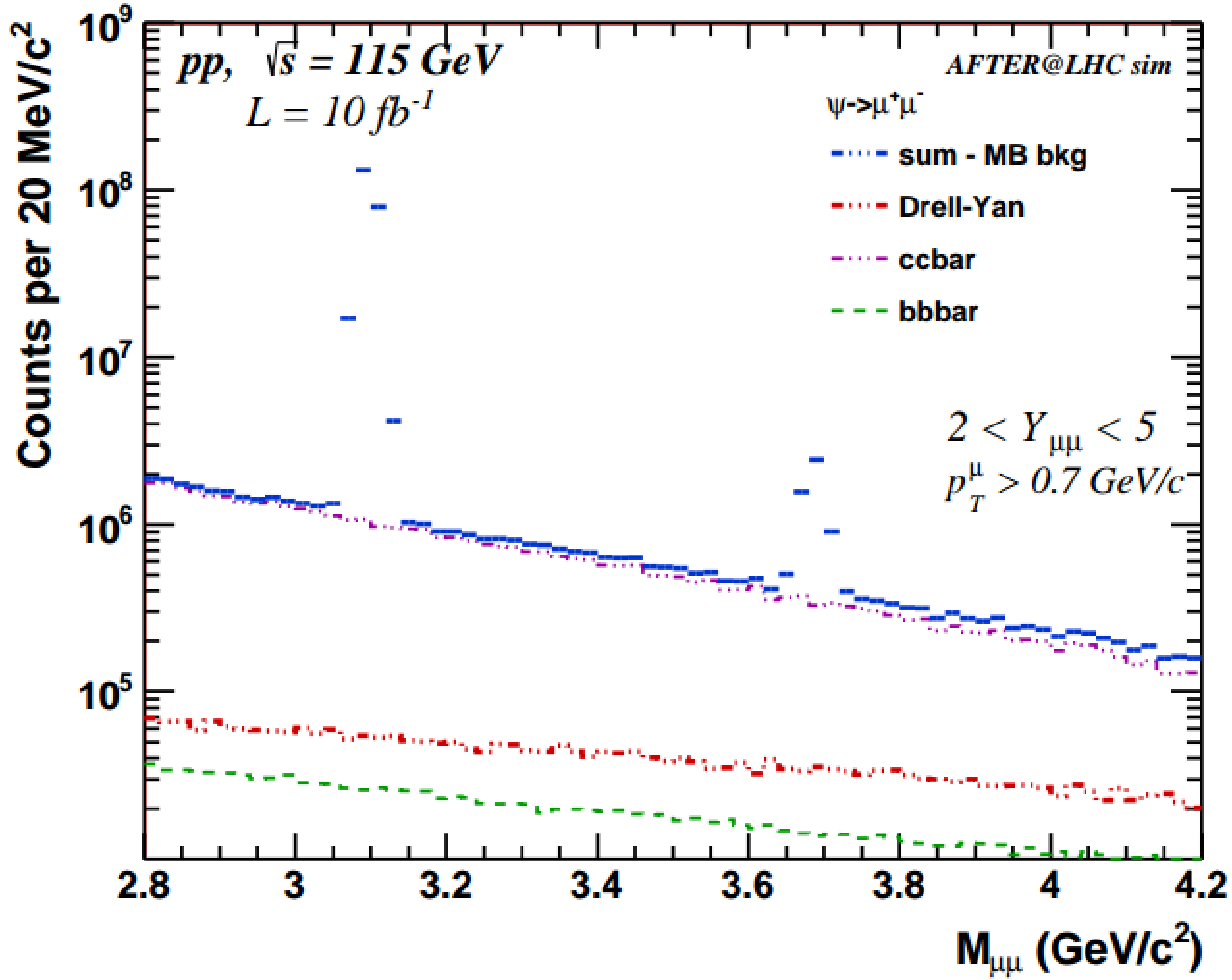
- Access to the tri-gluon correlation and the gluon Sivers effect ($\rightarrow L_g$)
- Differences in $A_N$ $D^0$ and $A_N$ $\overline{D^0}$ gives access to C-odd correlators

Precision at the per cent level



# J/ψ and Υ yields

Typically $10^9$ charmonia,
$10^6$ bottomonia per year



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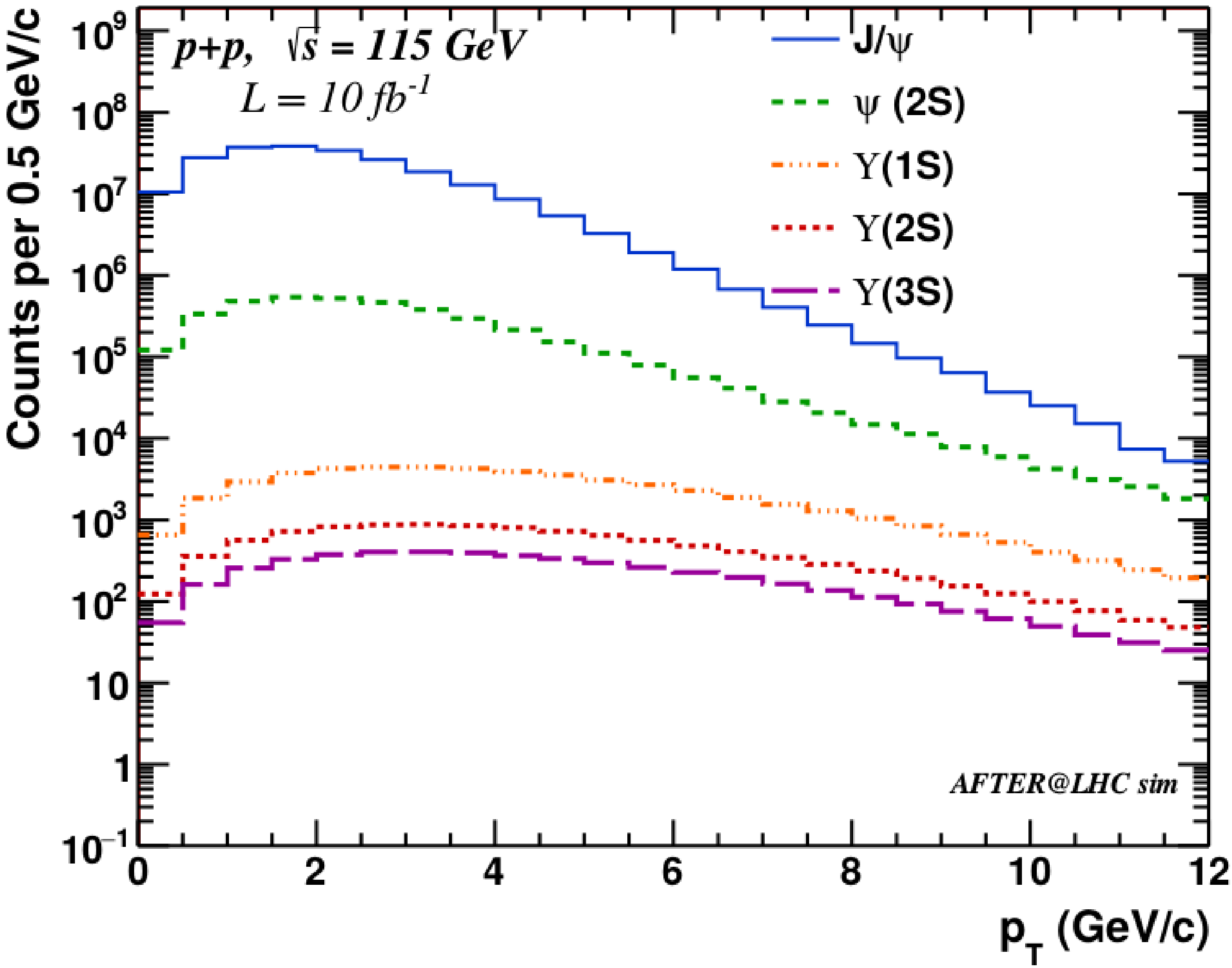
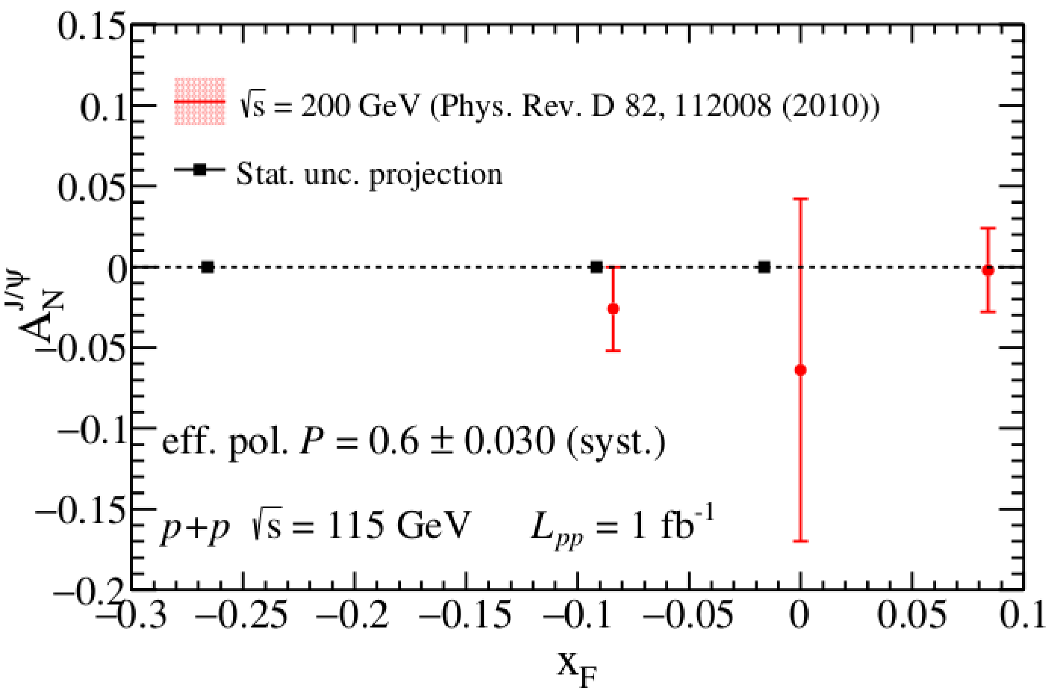
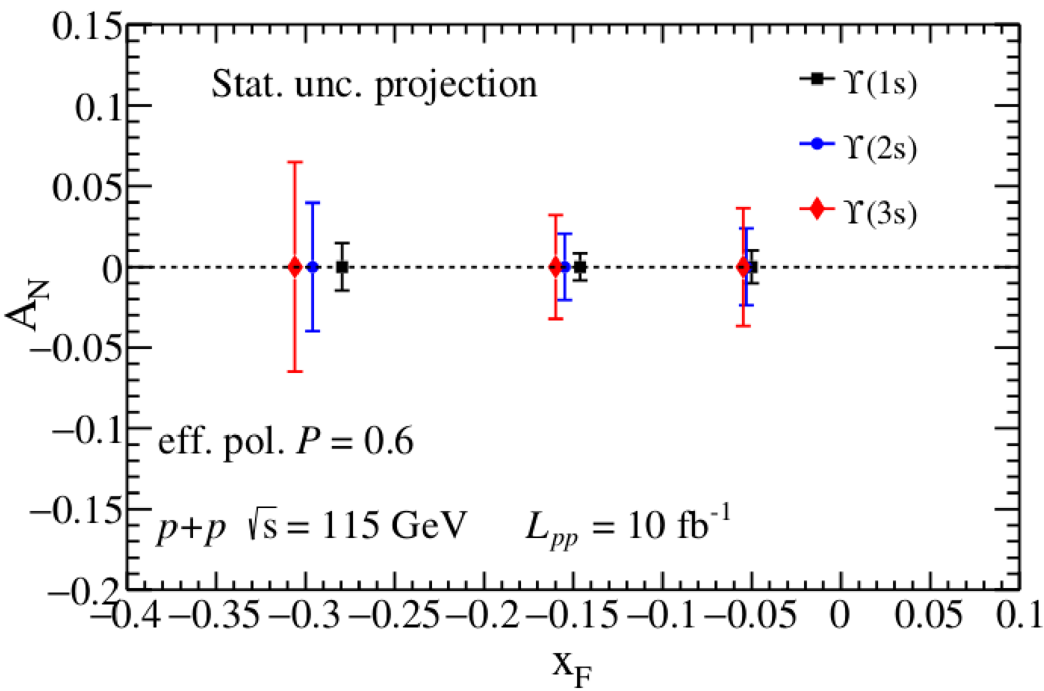


# Quarkonia $A_N$

- Unique access to C-even quarkonia ($\chi_{c,b}$, $\eta_c$ ) + associated production
- $A_N$ for all quarkonia (J/ψ, ψ', $\chi_c$ , ϒ(nS), $\chi_b$ & $\eta_c$ ) can be measured

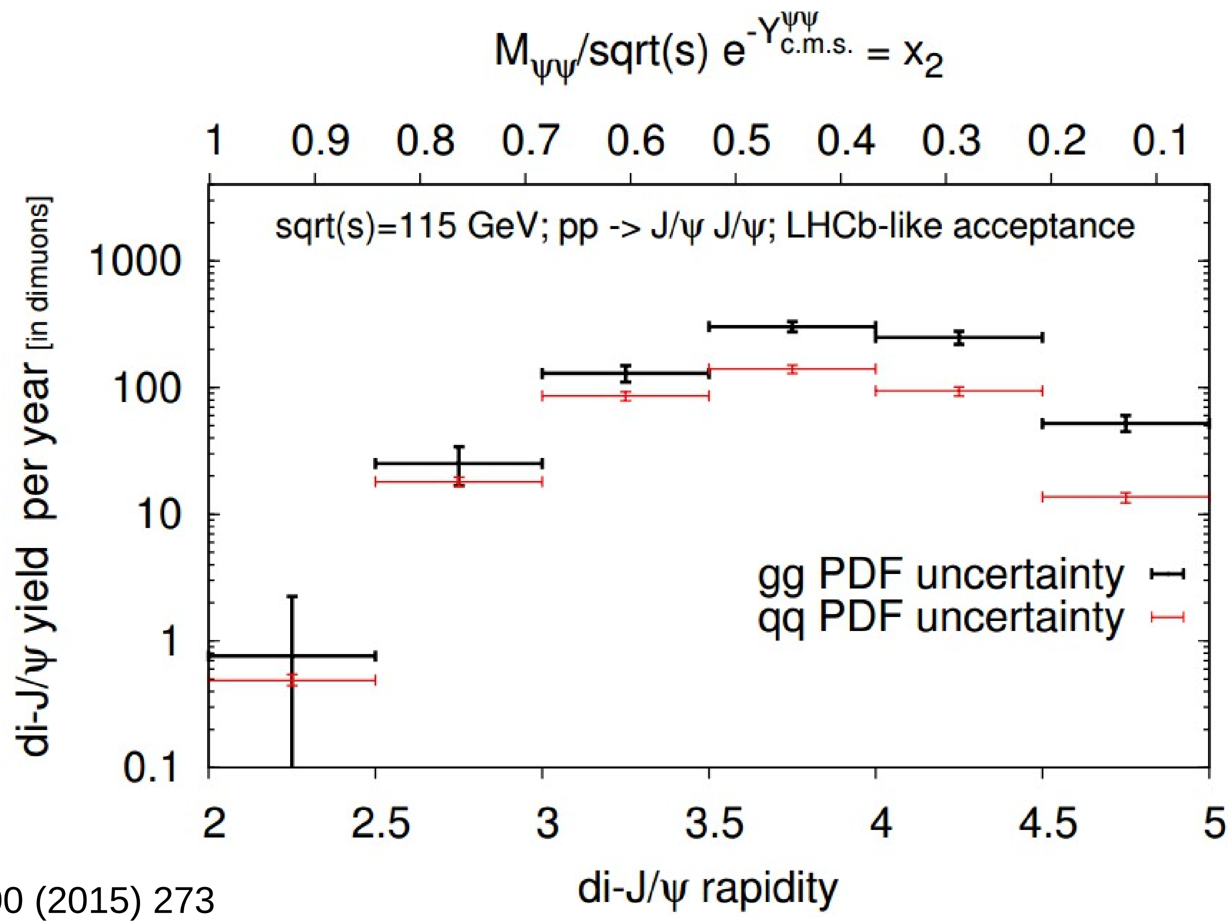



New perspectives to study the gluon Sivers effect (and beyond → $L_g$)

# Gluon Sivers effect via associated production

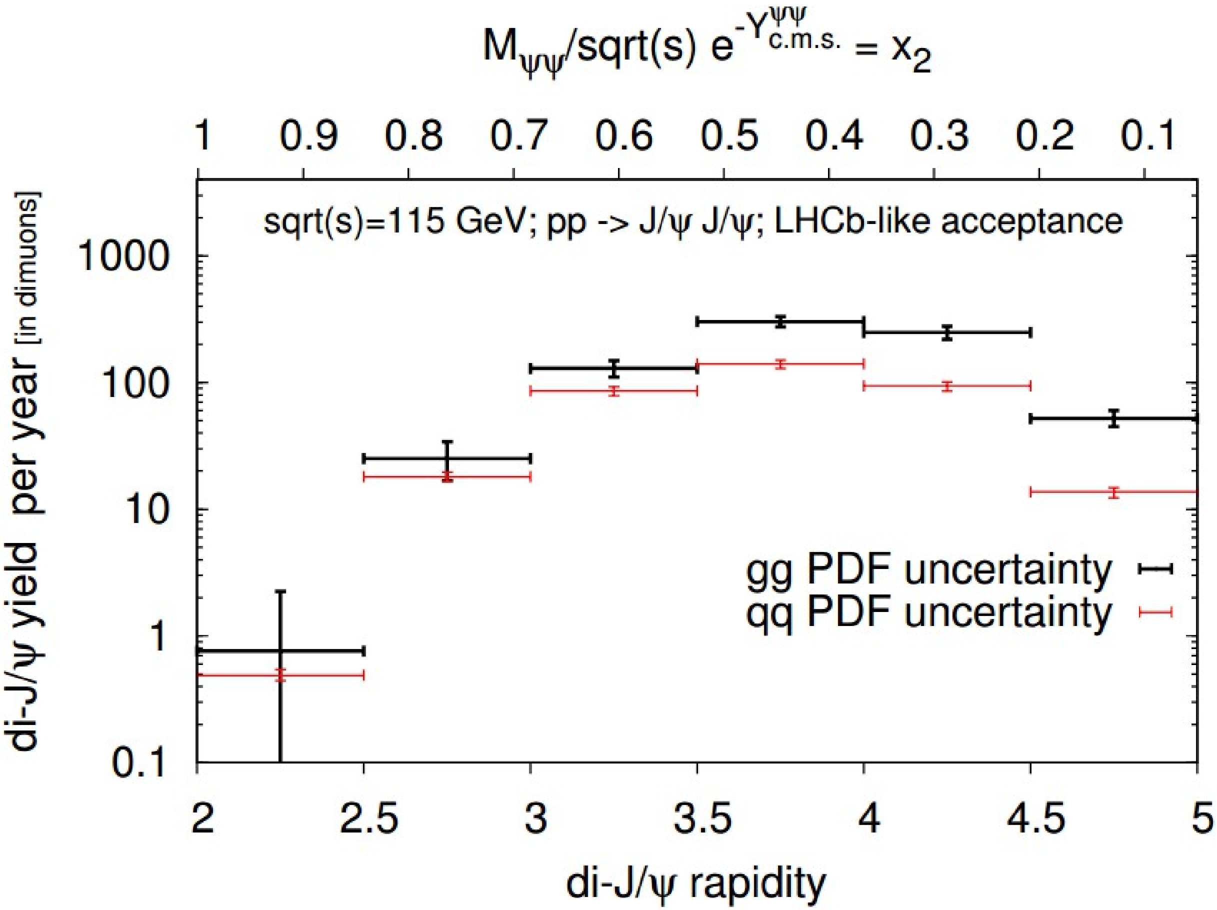
- J/ψ-J/ψ production (also J/ψ+γ, photon-pair)
  - clean probe of gluon TMD sector → gluon-induced process
  - produced colourless at low momenta




J.-P. Lansberg and Nucl. Phys. B 900 (2015) 273

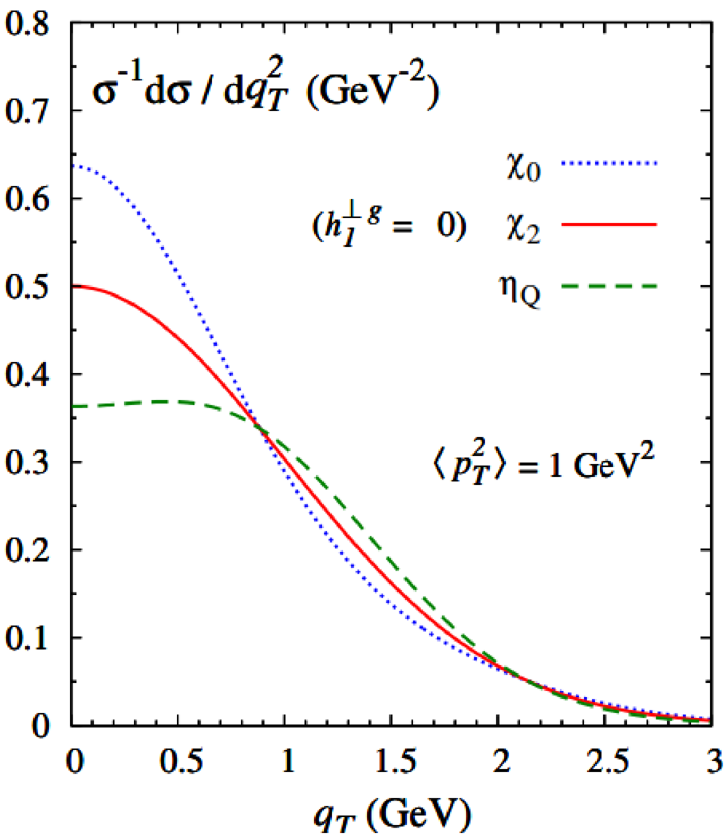
# Gluon Sivers effect via associated production

- $J/\psi$-$J/\psi$ production (also $J/\psi+\gamma$, photon-pair)
  - large yields, precise $A_N^{J/\psi\text{-}J/\psi}$
  - $A_N\left(p_T^{J/\psi\text{-}J/\psi}\right) \rightarrow k_T$ dependance of gluon Sivers function



# Distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$

- Access via:
  - back-to-back J/ψ+γ production [PRL 112, 212001 (2014)]
  - low $p_T$ C-even quarkonium [Phys. Rev. D 86, 094007]




$$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \;\&\; \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$

($R$ involves $f_1^g(x, k_T, \mu)$ and $h_1^{\perp g}(x, k_T, \mu)$)

**AFTER@LHC**:
possible to measure C-even quarkonia down to 0 $p_T$ and J/ψ+γ and J/ψ+J/ψ

→ determination of $h_1^{\perp g}$

# Other promising spin studies

- Azimuthal anisotropies beyond $A_N$ (e.g. transversity)
- Direct photon related observables
- Off-shell W production
- Ultra-peripheral collisions

# Summary & status

- A fixed-target program at the LHC can be implemented without interfering with the other experiments
- SMOG-LHCb → success story of an internal gas target at the LHC
- **Unique transverse spin program**
  - gluon transverse dynamics via heavy flavor probes
  - precision study of Sivers effect for quarks via Drell-Yan
- An Expression of Interest to be submitted to the LHC Experiments Committee (LHCC) is being written
- AFTER @ LHC: http://after.in2p3.fr

# Backup slides

# Physics opportunities in AFTER @ LHC

Physics opportunities of a fixed-target experiment using LHC beams

*Physics Reports 522 (2013) 239*

Ideas for a fixed target experiment at LHC in a Special Issue in Advances in High Energy Physics:

*Advances in High Energy Physics, Volume 2015 (2015)*

- **Heavy-ion physics**
- **Exclusive reactions**
- **Spin physics studies**
- **Hadron structure**
- **Feasibility study and technical ideas**

# Further readings: Spin physics

- Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment by K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak. [arXiv:1502.04021 [hep-ph]. Adv.Hi.En.Phys. (2015) 257934.
- Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment in a TMD factorisation scheme by M. Anselmino, U. D'Alesio, and S. Melis. [arXiv:1504.03791 [hep-ph]]. Adv.Hi.En.Phys. (2015) 475040.
- The gluon Sivers distribution: status and future prospects by D. Boer, C. Lorcé, C. Pisano, and J. Zhou. [arXiv:1504.04332 [hep-ph]]. Adv.Hi.En.Phys. (2015) 371396
- Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER) By T. Liu, B.Q. Ma. Eur.Phys.J. C72 (2012) 2037.
- Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER By D. Boer, C. Pisano. Phys.Rev. D86 (2012) 094007.

# Further readings: Feasibility study and technical ideas

- Feasibility studies for quarkonium production at a fixed-target experiment using the LHC proton and lead beams (AFTER@LHC) by L. Massacrier, B. Trzeciak, F. Fleuret, C. Hadjidakis, D. Kikola, J.P.Lansberg, and H.S. Shao arXiv:1504.05145 [hep-ex]. Adv.Hi.En.Phys. (2015) 986348
- A Gas Target Internal to the LHC for the Study of pp Single-Spin Asymmetries and Heavy Ion Collisions by C. Barschel, P. Lenisa, A. Nass, and E. Steffens. Adv.Hi.En.Phys. (2015) 463141
- Quarkonium production and proposal of the new experiments on fixed target at LHC by N.S. Topilskaya, and A.B. Kurepin. Adv.Hi.En.Phys. (2015) 760840

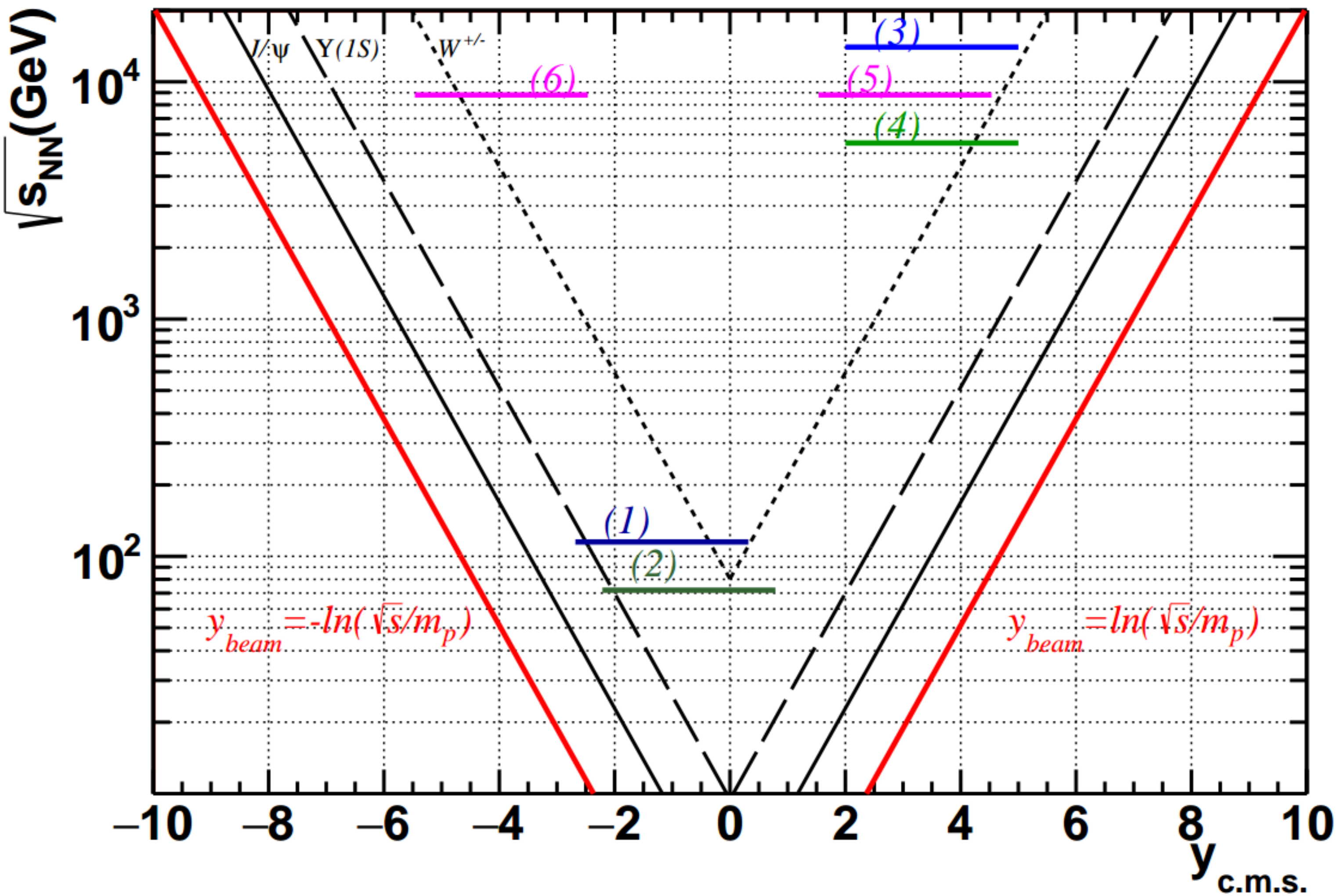
# Further readings: Hadron structure

- Double-quarkonium production at a fixed-target experiment at the LHC ( AFTER@LHC). by J.P. Lansberg, H.S. Shao. [arXiv:1504.06531 [hep-ph]]. Nucl.Phys. B900 (2015) 273-294
- Next-To-Leading Order Differential Cross-Sections for Jpsi, psi(2S) and Upsilon Production in Proton-Proton Collisions at a Fixed-Target Experiment using the LHC Beams (AFTER@LHC) by Y. Feng, and J.X. Wang. Adv.Hi.En.Phys. (2015) 726393.
- ηc production in photon-induced interactions at a fixed target experiment at LHC as a probe of the odderon By V.P. Goncalves, W.K. Sauter. arXiv:1503.05112 [hep-ph].Phys.Rev. D91 (2015) 9, 094014.
- A review of the intrinsic heavy quark content of the nucleon by S. J. Brodsky, A. Kusina, F. Lyonnet, I. Schienbein, H. Spiesberger, and R. Vogt. Adv.Hi.En.Phys. (2015) 231547.
- Hadronic production of $\Xi_{cc}$ at a fixed-target experiment at the LHC By G. Chen et al.. Phys.Rev. D89 (2014) 074020.

# Further readings: Heavy-Ion Physics

- Gluon shadowing effects on J/ψ and Y production in p+Pb collisions at $\sqrt{s_{NN}}$ = 115 GeV and Pb+p collisions at $\sqrt{s_{NN}}$ = 72 GeV at AFTER@LHC by R. Vogt. Adv.Hi.En.Phys. (2015) 492302.
- Prospects for open heavy flavor measurements in heavy-ion and p+A collisions in a fixed-target experiment at the LHC by D. Kikola. Adv.Hi.En.Phys. (2015) 783134
- Quarkonium suppression from coherent energy loss in fixed-target experiments using LHC beams by F. Arleo, S.Peigne. [arXiv:1504.07428 [hep-ph]]. Adv.Hi.En.Phys. (2015) 961951
- Anti-shadowing Effect on Charmonium Production at a Fixed-target Experiment Using LHC Beams by K. Zhou, Z. Chen, P. Zhuang. Adv.High Energy Phys. 2015 (2015) 439689
- Lepton-pair production in ultraperipheral collisions at AFTER@LHC By J.P. Lansberg, L. Szymanowski, J. Wagner. JHEP 1509 (2015) 087
- Quarkonium Physics at a Fixed-Target Experiment using the LHC Beams. By J.P. Lansberg, S.J. Brodsky, F. Fleuret, C. Hadjidakis. [arXiv:1204.5793 [hep-ph]]. Few Body Syst. 53 (2012) 11.

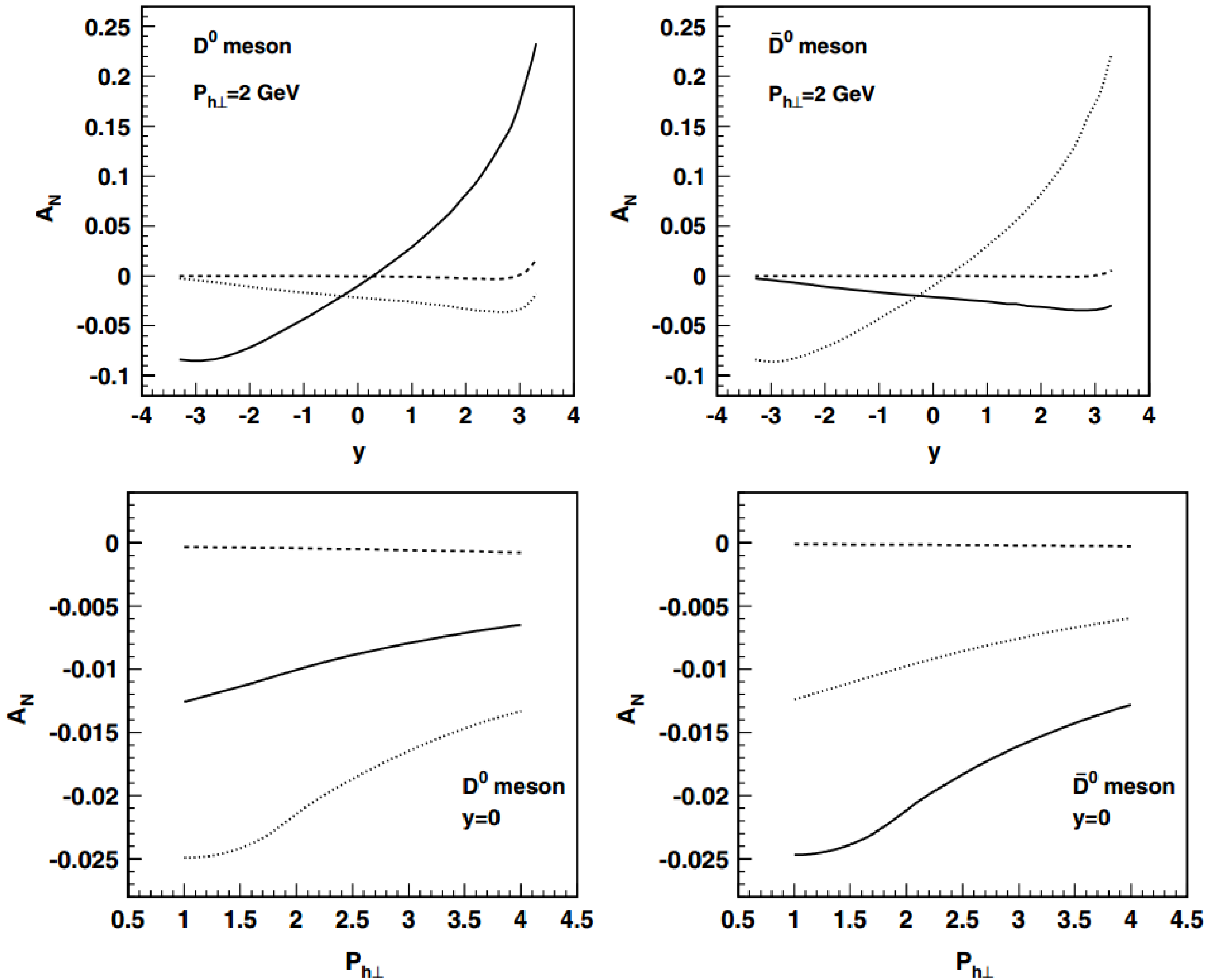
# Acceptance for LHCb-type detector




$2 < \eta^{lab} < 5$

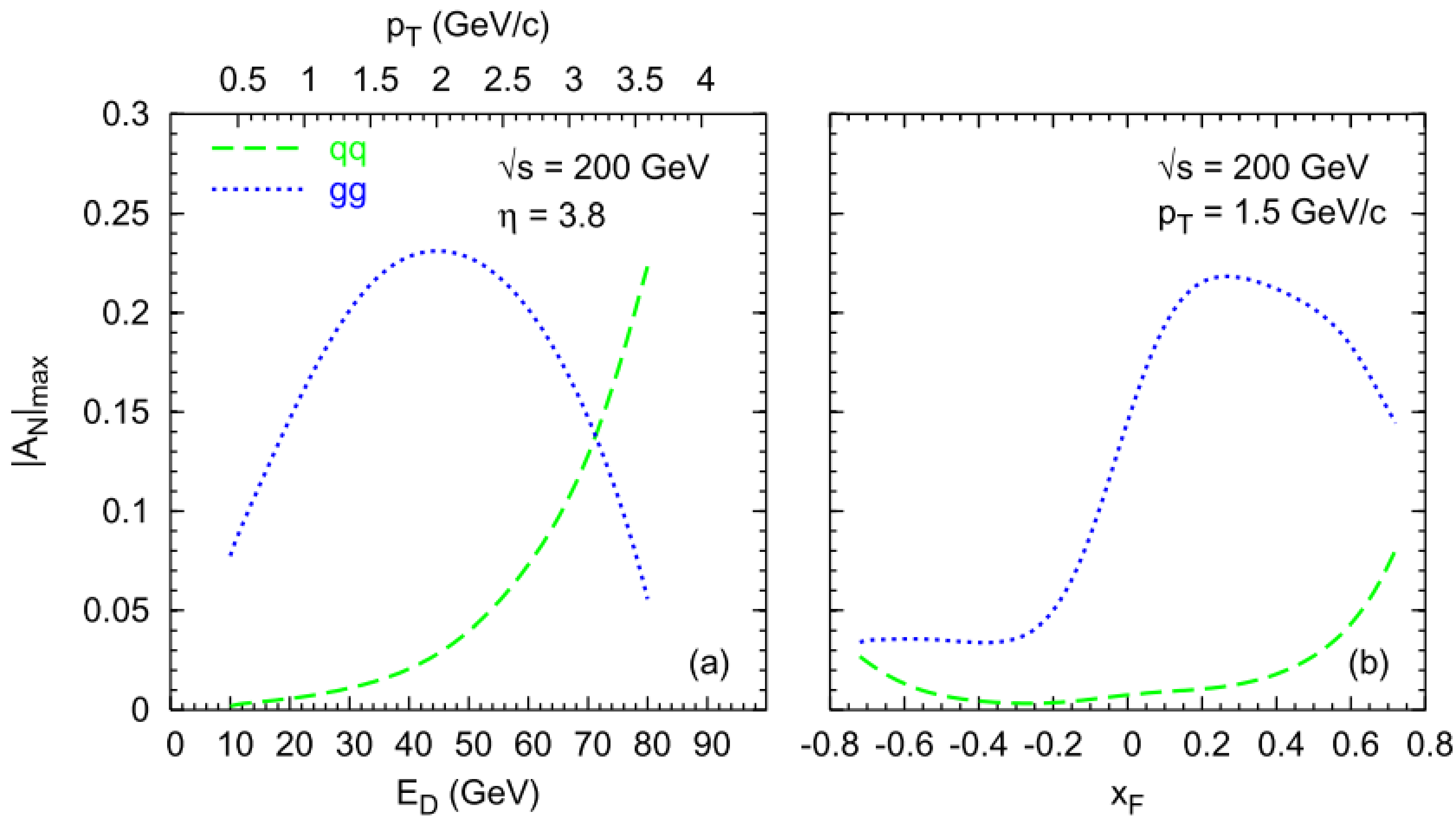
(1) p+A, fixed target, $\sqrt{s_{NN}}$ = 115 GeV; (2) Pb+A, fixed target, $\sqrt{s_{NN}}$ = 72 GeV;
(3) p+p, collider mode, $\sqrt{s}$ = 14 TeV; (4) Pb+Pb, collider mode, $\sqrt{s_{NN}}$ = 5.5 TeV,
(5) p+Pb, collider mode, $\sqrt{s_{NN}}$ = 8.8 TeV;
(6) Pb+p, collider mode, $\sqrt{s_{NN}}$ = 8.8 TeV.

# Twist-3 predictions




Z.-B. Kang, J.-W. Qiu, W. Vogelsang, F. Yuan, PRD 78, 114013 (2008)

# TMD predictions




$$x_F = x_1 - x_2, \quad x_1 = e^{y}\, m_T/\sqrt{s},\ x_2 = e^{-y}\, m_T/\sqrt{s},\ m_T^2 = m^2 + p_T^2$$

M. Anselmino, M. Boglione, U. D'Alesio, E. Leader, and F. Murgia, PRD 70 (2004) 074025

# Luminosities in p+p and p+A at 115 GeV

Instantaneous luminosity:

$$\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

*l* is a target thickness

**Extracted beam**

| Target | ρ (g.cm$^{-3}$) | A | L (μb$^{-1}$.s$^{-1}$) | ∫L (pb$^{-1}$.yr$^{-1}$) |
|---|---|---|---|---|
| Liq $H_2$ (1m) | 0.07 | 1 | 2000 | 20000 |
| Liq $D_2$ (1m) | 0.16 | 2 | 2400 | 24000 |
| Be (1cm) | 1.85 | 9 | 62 | 620 |
| Cu (1cm) | 8.96 | 64 | 42 | 420 |
| W (1cm) | 19.1 | 185 | 31 | 310 |
| Pb (1cm) | 11.35 | 207 | 16 | 160 |

**Internal gas target**

| Beam | Target | Usable gas zone (cm) | Pressure (Bar) | L (μb$^{-1}$.s$^{-1}$) | ∫L (pb$^{-1}$.yr$^{-1}$) |
|---|---|---|---|---|---|
| p | Perfect gas | 100 | $10^{-9}$ | 10 | 100 |

*With pressure of $10^{-6}$ mbar - 3 times SMOG – one gets 100 pb$^{-1}$ yr$^{-1}$*

→ target storage cell that can be **polarised**

P = $10^{-4}$ mbar

Advances in High Energy Physics, Volume 2015 (2015), Article ID 463141

**Integrated luminosities with $10^7$ s** (LHC year – 9 months of running)

**For 1m long $H_2$ target**

$$\int\mathcal{L} = 20\ \text{fb}^{-1}\text{yr}^{-1}$$

$$\int\mathcal{L} = 10\ \text{fb}^{-1}\text{yr}^{-1}$$ for P = $10^{-4}$ mbar

Large luminosities comparable to LHC, 3 orders of magnitude larger that at RHIC

Similar integrated luminosities in **pA** in the target storage cell case as with the extracted beam option

# Luminosities in A+A at 72 GeV

Instantaneous luminosity:

$$\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

*l* is a target thickness

**Extracted beam**

| Target | ρ ($g.cm^{-3}$) | A | L ($\mu b^{-1}.s^{-1}$) | $\int$L ($pb^{-1}.yr^{-1}$) |
|---|---|---|---|---|
| Liq $H_2$ (1m) | 0.07 | 1 | 0.8 | 0.8 |
| Liq $D_2$ (1m) | 0.16 | 2 | 1 | 1 |
| Be (1cm) | 1.85 | 9 | 0.025 | 0.025 |
| Cu (1cm) | 8.96 | 64 | 0.017 | 0.017 |
| W (1cm) | 19.1 | 185 | 0.013 | 0.013 |
| Pb (1cm) | 11.35 | 207 | 0.007 | 0.007 |

**Internal gas target**

| Beam | Target | Usable gas zone (cm) | Pressure (Bar) | L ($\mu b^{-1}.s^{-1}$) | $\int$L ($pb^{-1}.yr^{-1}$) |
|---|---|---|---|---|---|
| Pb | Perfect gas | 100 | $10^{-9}$ | 0.001 | 0.001 |

$P = 10^{-6}$ *mbar*

→ target storage cell that can be **polarised**

**Integrated luminosities with $10^6$ s** (Pb LHC year – 1 months of running)

**For 1m long $H_2$ target**

$$\int\mathcal{L} = 0.8\ pb^{-1}yr^{-1}$$

**For 1cm long Pb target**

$$\int\mathcal{L} = 7\ nb^{-1}yr^{-1}$$

$$\int\mathcal{L} = 0.001\ pb^{-1}yr^{-1} \qquad P = 10^{-6}\ mbar$$

Nominal LHC collider luminosity for PbPb: 0.5 $nb^{-1}$

# SMOG-LHCb data

p+Ne pilot run at $\sqrt{s_{NN}}$ = 87 GeV (2012) ~ 30 min

Pb+Ne pilot run at $\sqrt{s_{NN}}$ = 54 GeV (2013) ~ 30min

p+Ne run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 12h

p+He run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 8h

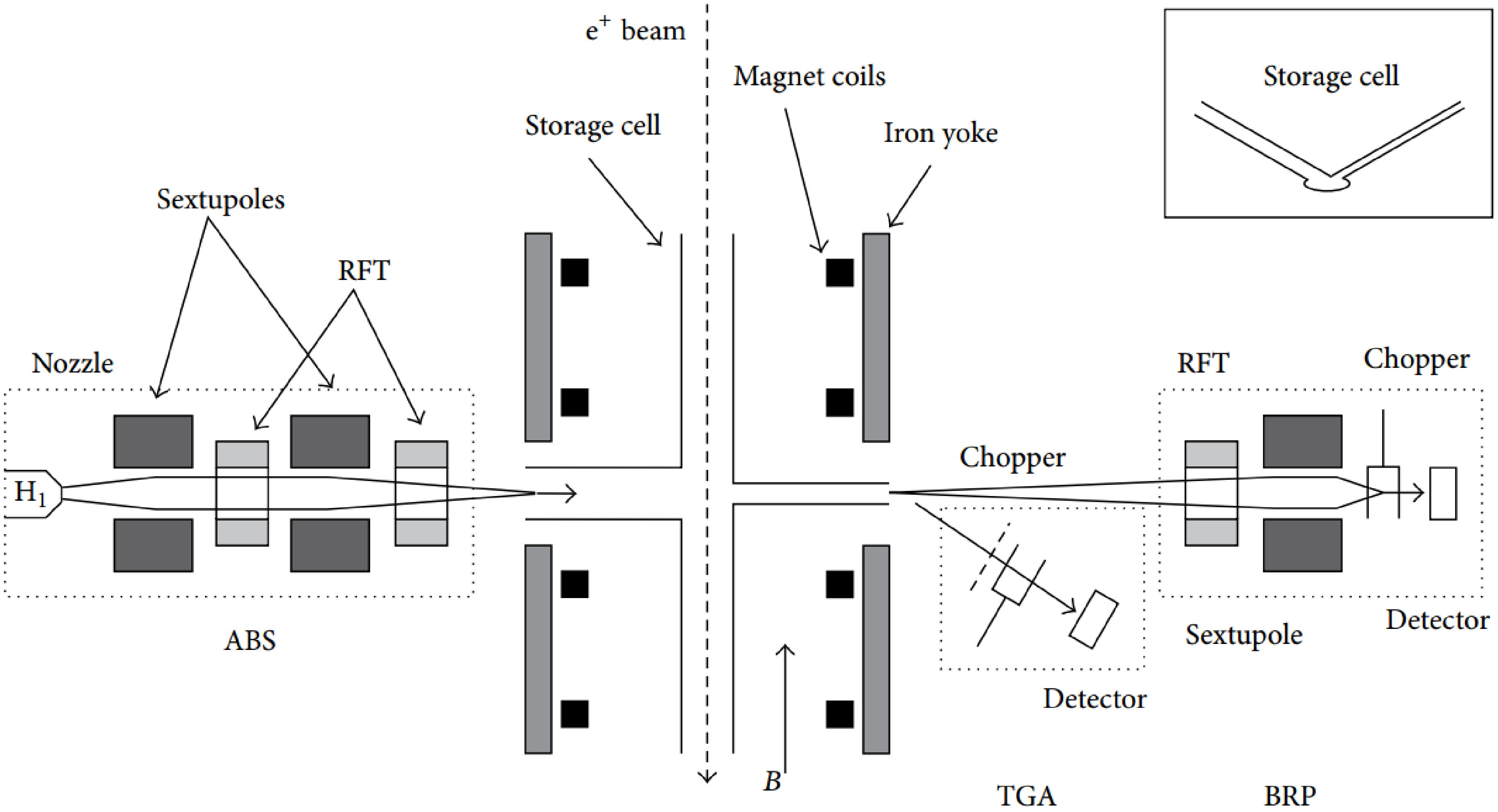
p+Ar run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 3 days

p+Ar run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ few hours

Pb+Ar run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ 1.5 week

p+He run at $\sqrt{s_{NN}}$ = 110 GeV (2016) ~ 2 days

# HERMES-type system




From left to right: Atomic Beam Source (ABS), target chamber with cell and SC magnet coils, diagnostic system of target gas analyzer (TGA), and Breit-Rabi polarimeter (BRP).

HERMES Collaboration, A. Airapetian et al, Nucl. Instr. Meth. A540 (2005) 68,
Advances in High Energy Physics, Volume 2015, Article ID 463141

# Available Luminosities

| Beam | Target | $A$ | Areal density ($\theta$) (cm$^{-2}$) | $\mathscr{L}$ ($\mu$b$^{-1}$.s$^{-1}$) | $\int \mathscr{L}$ (fb$^{-1}$.y$^{-1}$) |
|---|---|---|---|---|---|
| $p$ | H | 1 | $2.5 \times 10^{14}$ | 900 | 9 |
| $p$ | D | 2 | $3.2 \times 10^{14}$ | 1200 | 12 |

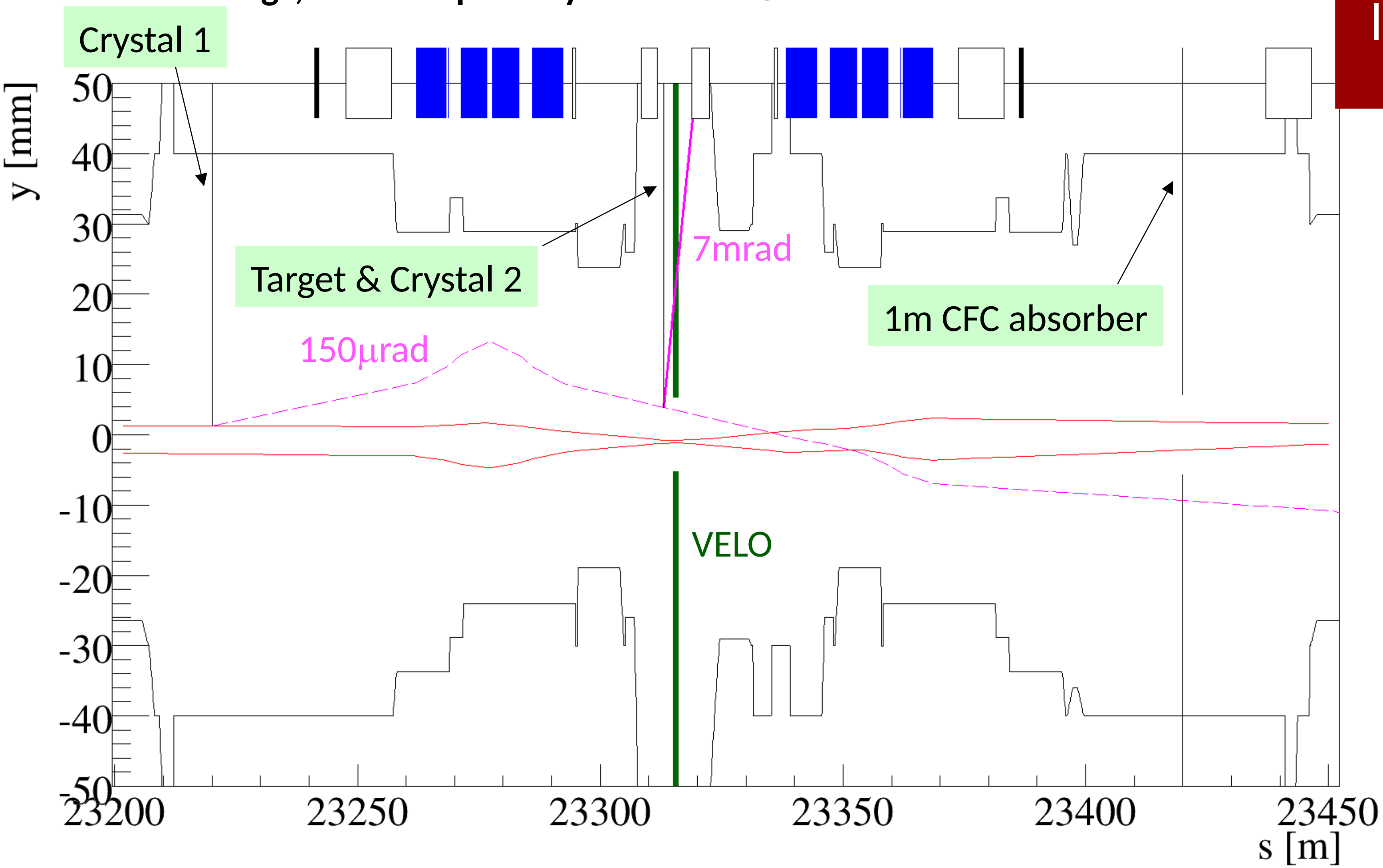
(b) Polarised internal-gas-target option

PoS PSTP2015 (2015) 042, arXiv:1602.06857

# Layout for the measurement of Short Living Baryon Magnetic Moment using Bent Crystals at LHC.

***All devices placed in available slots in IR8***

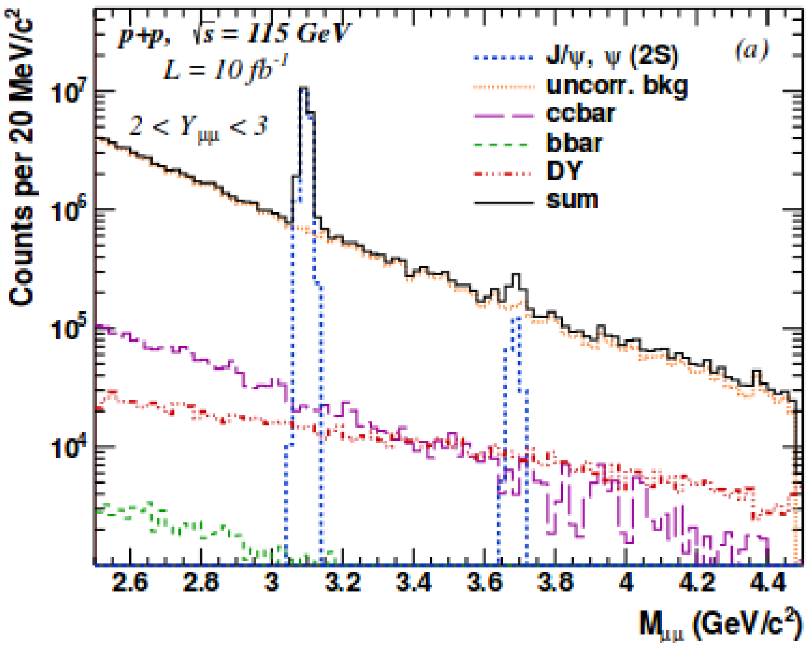
**The crystal 1 is at 5.0 σ from the center-line, whilst the collimation system has the 2016 nominal settings, with the primary TCP at 5.5 σ.**

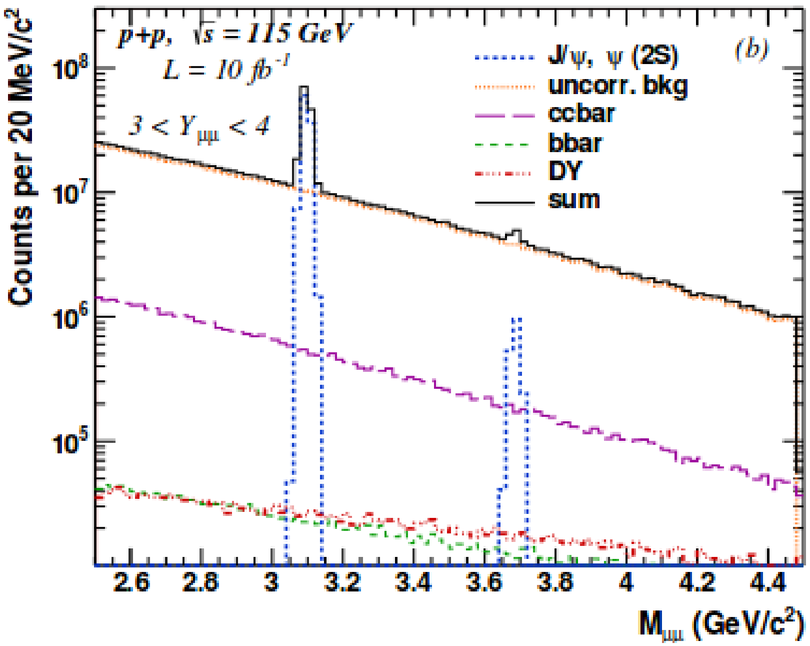


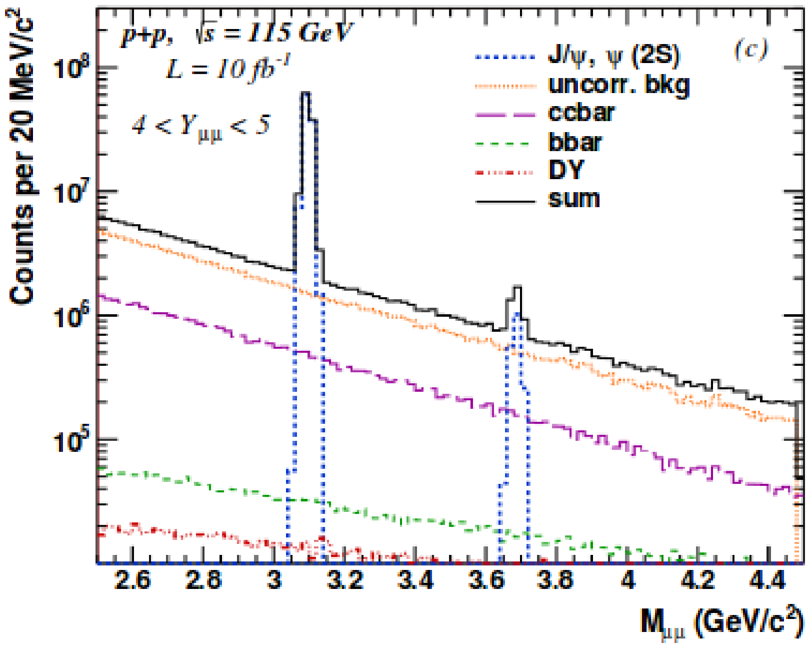

layout with LHCb det.

W. Scandale, Physics Beyond Colliders, CERN, 06/09/2016

# Example: J/ψ



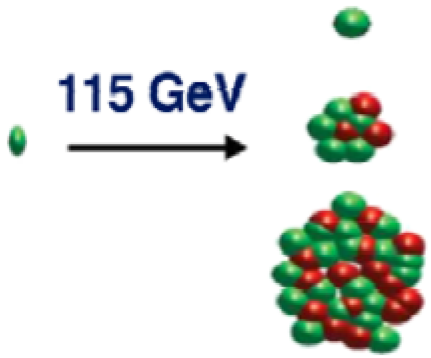




Typically $10^9$ charmonia, $10^6$ bottomonia per year

Adv. High Energy Phys. 2015 (2015) 986348

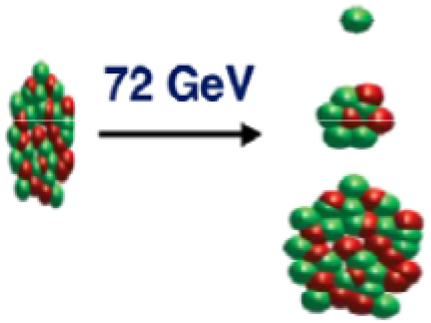
# Kinematics

- p+p or p+A with a 7 TeV p on a fixed target




$$\sqrt{s} = \sqrt{2 m_N E_p} \approx 115\, GeV$$
$$y_{CMS} = 0 \rightarrow y_{Lab} = 4.8$$

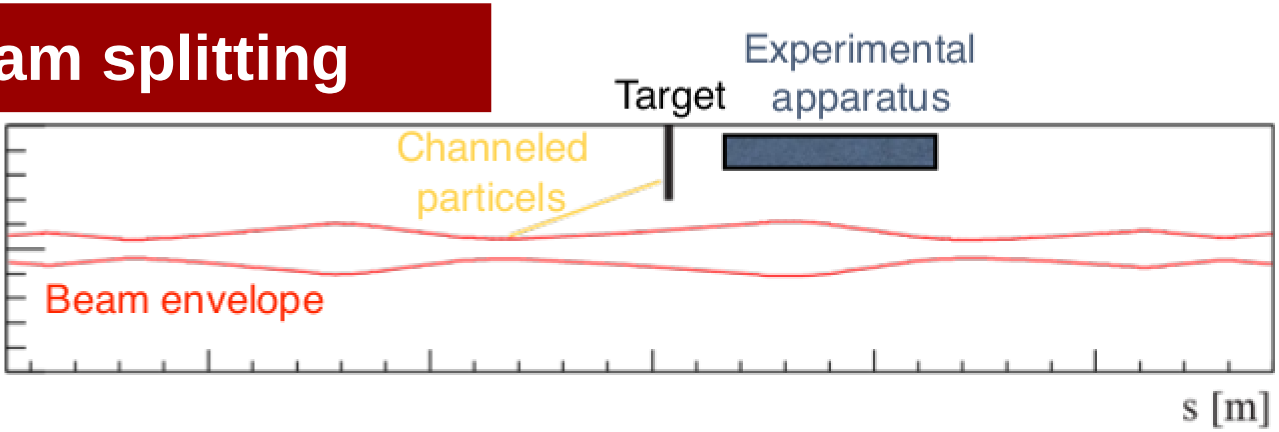
- A+A collisions with a 2.76 TeV Pb beam




$$\sqrt{s} \approx 72\, GeV$$
$$y_{CMS} = 0 \rightarrow y_{Lab} = 4.3$$

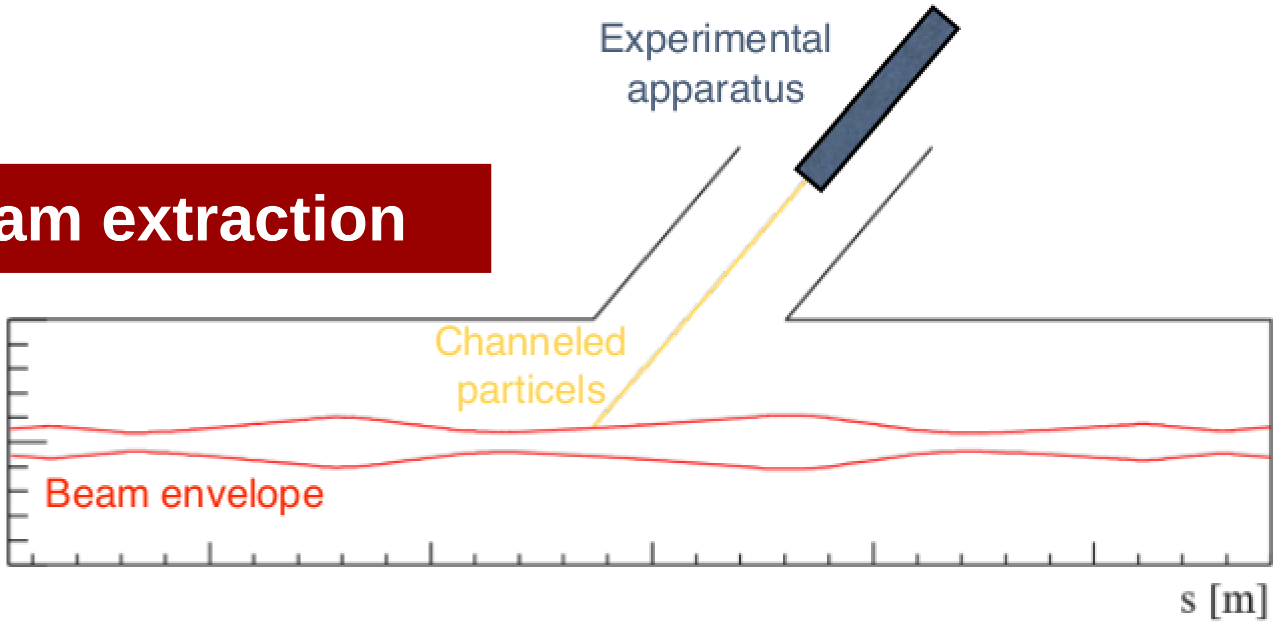
# Beam splitting by a bent crystal

## Beam splitting




S. Redaelli, Physics Beyond Colliders, CERN, 06/09/2016

## Beam extraction




→ intermediate option, reduces the civil engineering
→ similar fluxes as for beam extraction (new beam line)
→ might be coupled to an existing experiment

# Drell-Yan production