



First thoughts on polarized protons in the FCC and injectors

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About this presentation

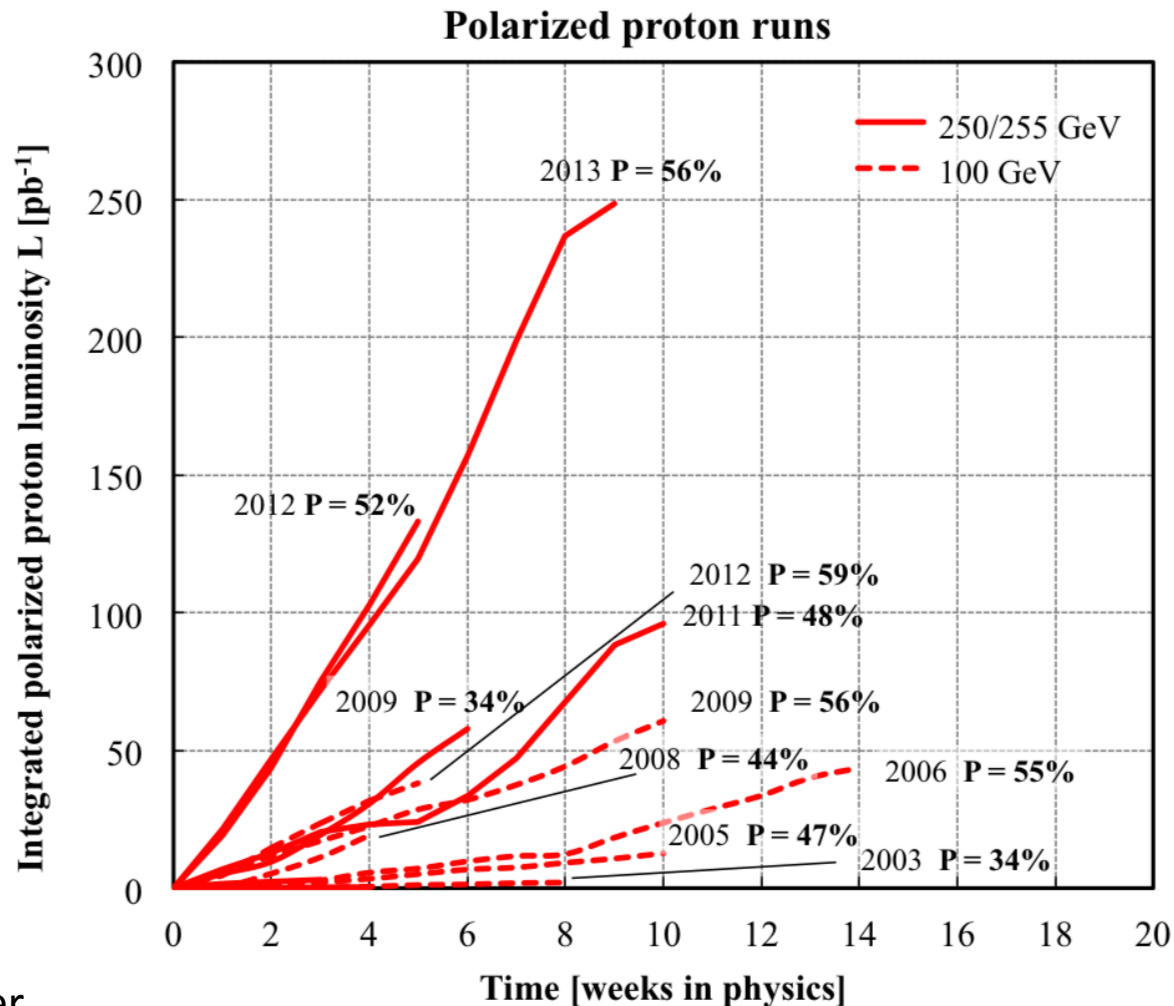
- Section by Mei Bai
 - Review of RHIC polarized protons
 - Extrapolations to LHC
- Section by John Jowett
 - Very preliminary thoughts about what might be done with FCC-hh and its injectors
 - Remarks about potential for EDM (p and deuteron)
- Everything prepared at short notice without much opportunity for discussion

SECTION BY MEI BAI

Reaching High Energy Polarized Protons Beyond RHIC?

Status of High Energy Polarized Protons

•RHIC has successfully accelerated polarized protons upto 255GeV with the dual snake setup. Polarization loss between injection and 100 GeV is negligible. 5-10% polarization loss between 100 GeV and 255 GeV was observed. Average store polarization of $\sim 55\%$ was achieved.



•Courtesy of W. Fischer

Polarized protons in the LHC injection chain

- PS: beam energy similar to the AGS. Can use similar strategy, i.e. double partial snakes to overcome both imperfection and intrinsic spin resonances

- A strong partial Siberian snake generates large spin tune gap for $G\gamma = n$. With strong enough snake, gap is large enough to cover both imperfection and intrinsic spin resonances.

•Imperfection resonance

- Note: With a strong snake, the stable spin direction will deviate from vertical direction

□Intrinsic resonance

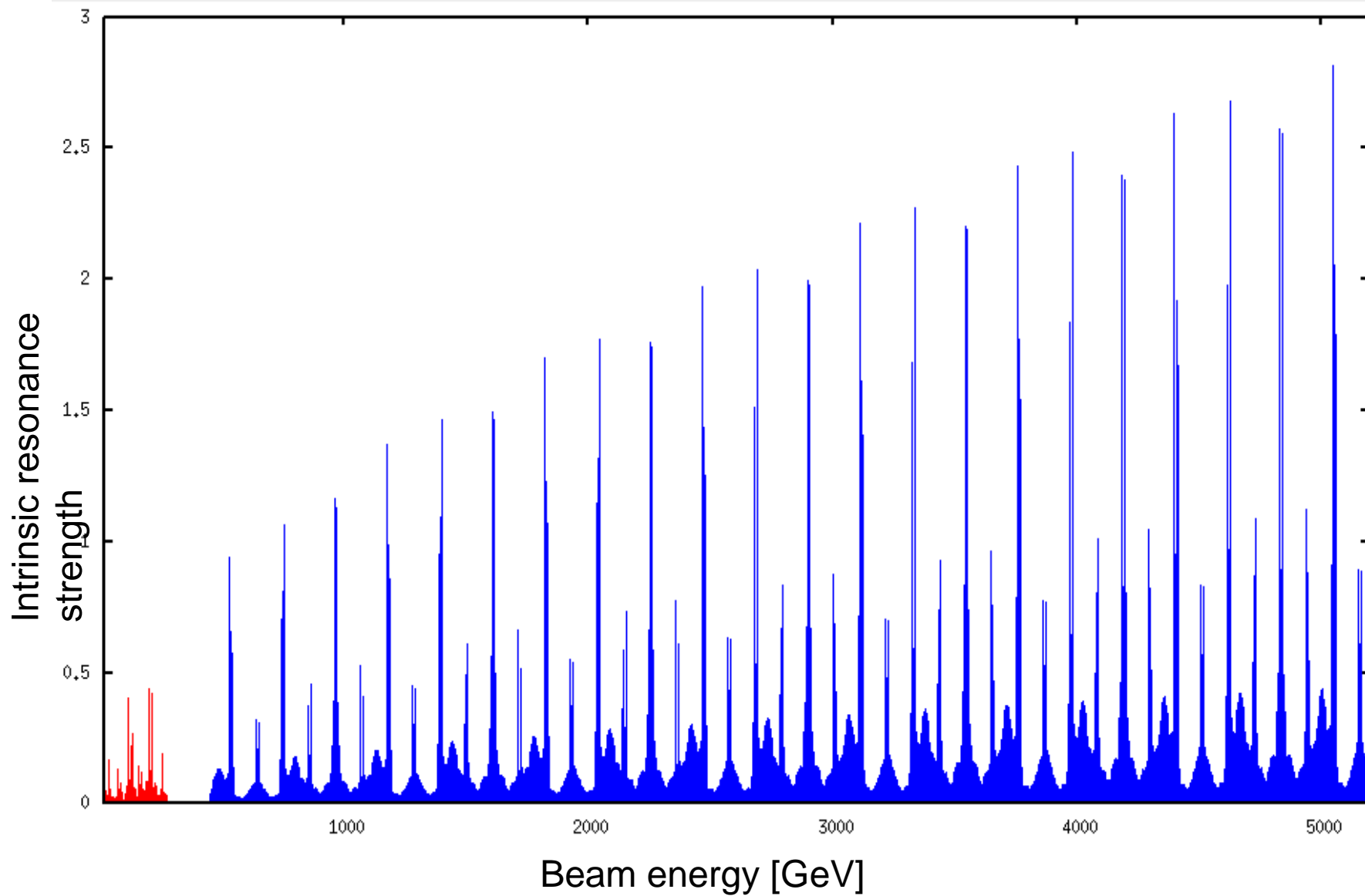
Polarized protons in the LHC injection chain

- SPS: much higher energy than RHIC
 - Intrinsic spin resonance $\varepsilon \sim \sqrt{\beta\gamma}$. i.e. the intrinsic resonance is about 40% stronger at 450GeV than the strong resonance in RHIC at 255GeV.
 - Imperfection resonance $\varepsilon \sim \beta\gamma$
 - Tighter tolerance for beam parameters

	Yrms required	Yrms achieved	ΔQ_y required	ΔQ_y achieved
RHIC	0.5 mm	0.1 mm	0.003	0.005
SPS	0.28 mm	--	(need simulation to find out)	--

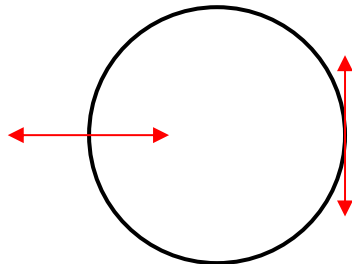
- Recommend 3-pair snake setup for preserving polarization
- Question, can the SPS lattice accommodate multiple snakes?

For LHC

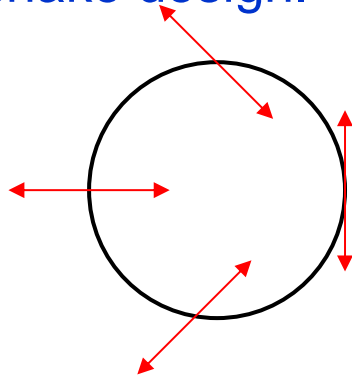


For LHC

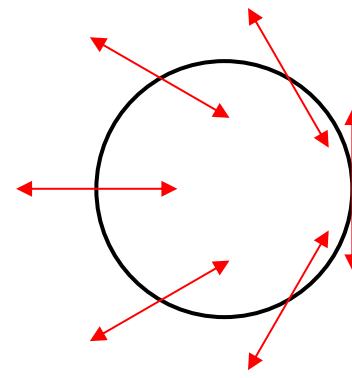
•S.R. Mane showed that for a single strong intrinsic resonance the spin tune does not depend on the beam emittance if the snake axes angle increases in equal steps from one snake to the next. This may be a good starting point for a multiple snake design.



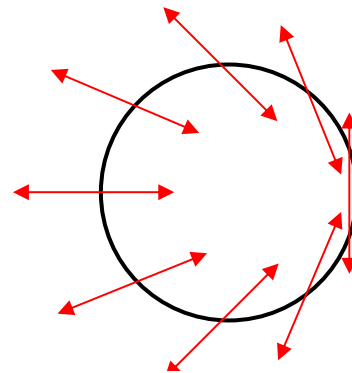
▫2 Snakes (RHIC)
▫ $\Delta\alpha = 90^\circ$



▫4 Snakes (HERA-p?)
▫ $\Delta\alpha = 45^\circ$



▫6 Snakes (Tevatron?)
▫ $\Delta\alpha = 30^\circ, 90^\circ$



▫8 Snakes (HERA-p?)
▫ $\Delta\alpha = 22.5^\circ, 67.5^\circ$

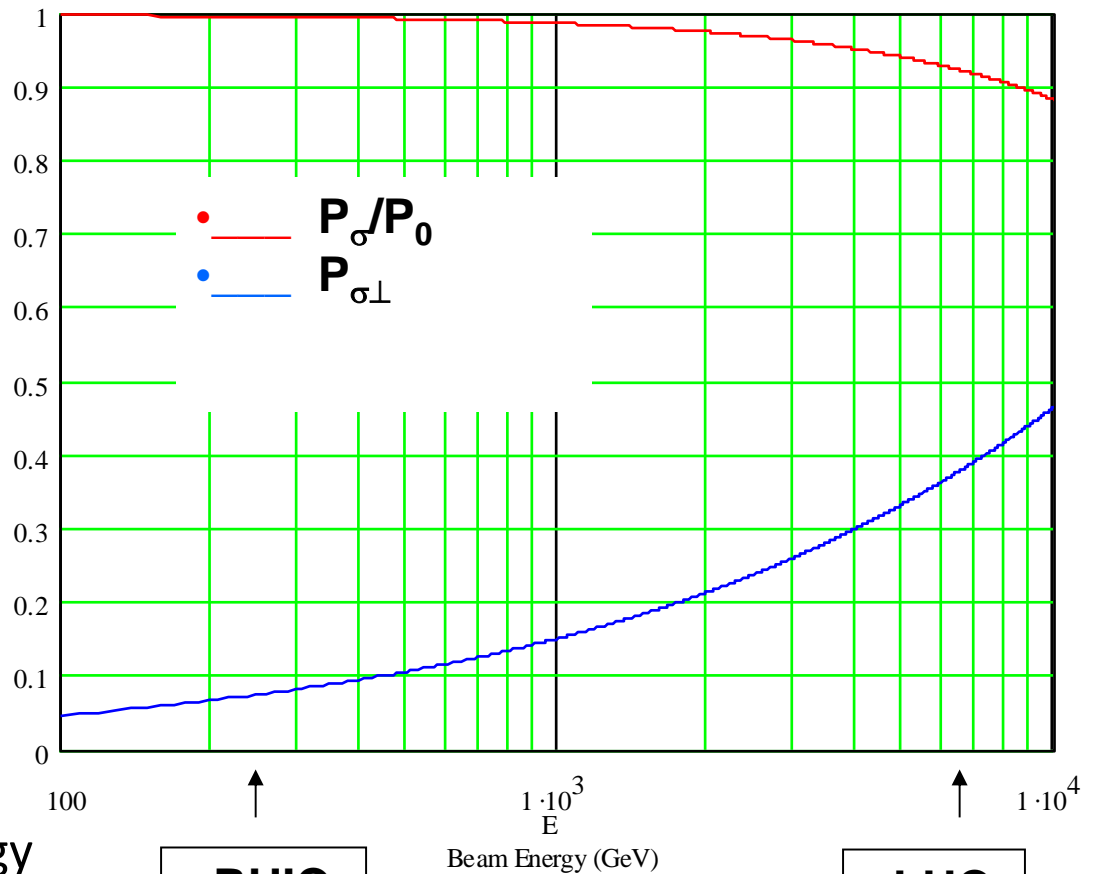
▫16 Snakes (LHC, replace 2 dipoles
▫per arc with snakes, $\Delta E \sim 1.4\%$)
▫ $\Delta\alpha = 11.25^\circ, 33.75^\circ, 56.25^\circ, 78.75^\circ$

T. Roser “The Future of High Energy Polarized Proton Beams”, Spin Symposium, 2008, Charlottesville, VA

□ Polarization at low beta IR

- Strong focusing in final focus triplets reduces beam polarization at IR

- Spin rotation in triplet:



T. Roser “The Future of High Energy Polarized Proton Beams”, Spin Symposium, 2008, Charlottesville, VA

□ RHIC

□ LHC

Summary

- RHIC showed it is plausible to have polarized protons upto high energy
- It is possible to build up polarized protons

SECTION BY JOHN JOWETT

Context

- No polarized proton beams at CERN so far
 - Some studies in the past
- Studies elsewhere
 - Earlier proton synchrotrons (ZGS, Saturne, AGS, ...)
 - Studies for HERA-p, SSC, ... invoking ideas of resonance compensation, Siberian Snakes, ...
 - In recent years the very impressive success of RHIC operating as a polarized proton collider demonstrated many of the theoretical ideas

Questions to be answered

- Are proton/deuteron EDM experiments possible at CERN ?
- Assuming that the present injector chain up to LHC is used to inject into FCC-hh rings, can the existing machines be modified to accelerate polarized protons up to 4 TeV for injection into FCC-hh ?
- Can polarization be preserved through acceleration up to 50 TeV in FCC-hh ?
 - How much complication does this add to FCC project ?

Earlier study for PS

CERN/PS/DL/76-9
23.7.1976.

THE FEASIBILITY OF ACCELERATING POLARIZED PROTONS IN THE CERN-PS AND OTHER STRONG FOCUSING MACHINES*

M. Bell, P. Germain, W. Hardt, W. Kubischta, P. Lefèvre, D. Möhl.
CERN, 1211 Geneva 23, Switzerland.

ABSTRACT

A proposal was made in January, 1975, for a study on the possibility of accelerating polarized protons in the CERN-PS. This is a report of the work performed and the conclusions reached, before the study was wound up. The following problems are discussed: improvements of the source, multi-turn injection into the PS, a collector ring between the preaccelerator and the Linac, depolarizing effects in the PS, and in the transport lines. The conclusions at the end of 1975 were that we should aim for 12 GeV/c as maximum momentum in the first place, but remain hopeful about the possibility of attaining higher PS energies. The results are scaled to other machines to show that polarized protons in, for example, the SPS are unlikely.

Considered keeping Linac1 for
polarized protons beside Linac2

Observation

Colliding polarized protons is a lot more complicated than colliding unpolarized protons!

Polarized protons for EDM at CERN?

- Requires injection of polarized protons at special low energy (KE 250 MeV)
- Could accelerate in Linac4, inject in special ring (YS talk?) from PS Booster
 - Needs alternative polarized source
 - Cf BNL source, current somewhat lower than design for Linac4 unpolarised source
 - Acceleration in Linac4 preserving H⁻ polarization likely OK
 - Compensate few depolarizing resonances in ramp of Booster (all 4 rings?), needs good control of orbit, etc.
 - Polarimetry ...
- All probably feasible with necessary effort but no obvious synergy, and could even interfere, with normal LHC/FCC operation.
 - Build another Linac → independent complex

RHIC polarized proton complex

To get an idea of what is needed:

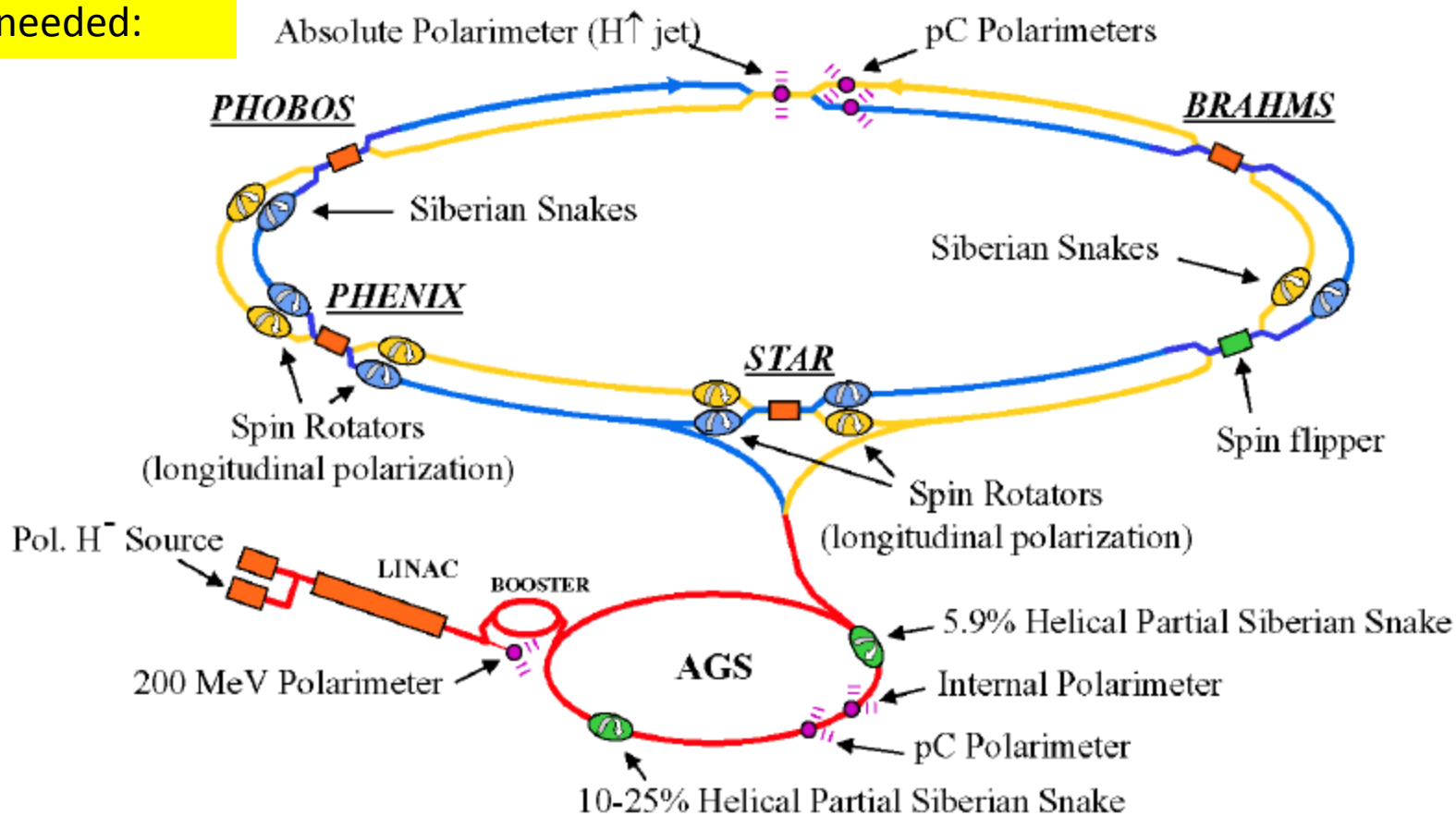
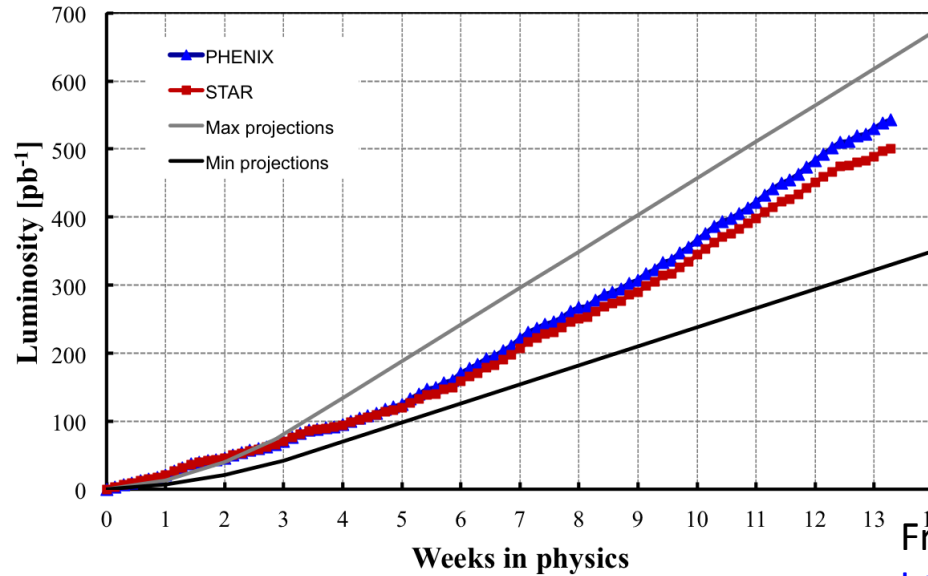


FIGURE 4. The RHIC accelerator complex with the elements required for the acceleration and collision of polarized protons highlighted.

From T. Roser, SPIN2008

RHIC Run13 $p\uparrow p\uparrow$ Delivered Luminosity ($\sqrt{s}=510$ GeV)



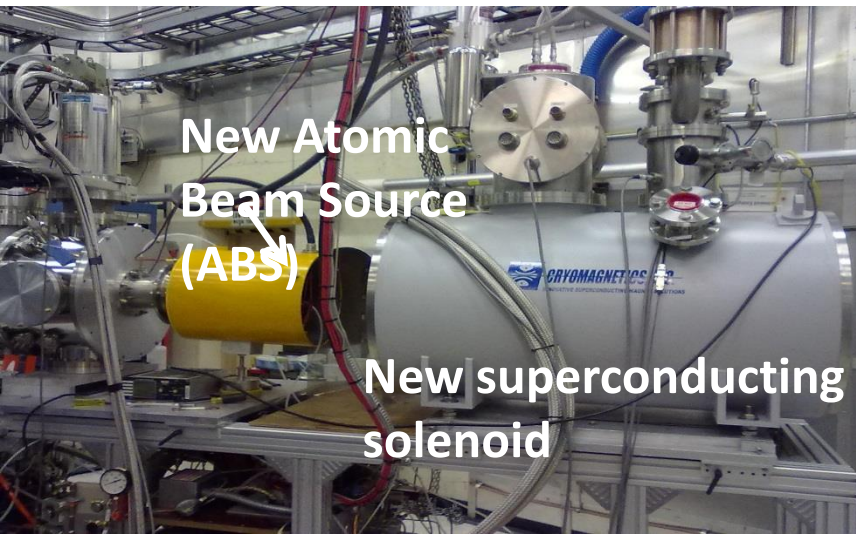
$> 0.5 \text{ fb}^{-1}$ $p\uparrow+p\uparrow$ luminosity from Run-13 exceeds all previous $p\uparrow+p\uparrow$ runs combined

From W. Fischer, BNL C-AD MAC, Dec 2014

<https://indico.bnl.gov/conferenceDisplay.py?confId=898>

stores with highest average pol.

new polarized source



H-jet measured polarization

(average over intensity, time, 14 best stores)

	Run-12	Run-13
Blue	52.0%	57.0%
Yellow	58.2%	57.7%

Source, Linac4, PS Booster

- RHIC OPPIS/ABS H⁻ source works well
 - Install alternative source of similar type for Linac4, would deliver somewhat lower beam current than unpolarized source
 - Linac4 cannot accelerate deuterons (might be possible with new ion source and Linac3)
 - Polarization through Linac4 probably OK.
 - Transfer to PS Booster ?
 - Acceleration in PS Booster probably OK with careful compensation of a few depolarizing resonances.

PS, SPS, LHC, RHIC

- Strategy established at RHIC could work in PS, SPS - see earlier slides by MB
 - Need to check space for new equipment like snakes (variable direction dipole fields, eg, helical magnets at BNL)
 - 90° Siberian Snake = 2.75 T m of dipole bending magnets
- Not clear how far one can go with LHC, FCC-hh
 - Resonances become very strong (see slide by MB)
 - Seems to require extreme orbit tolerances
 - Many snakes, probably OK if included in design of FCC-hh, need to find space in LHC
 - Polarimetry at high energy ?

Conclusions (all tentative!)

- If there is a strong physics case for polarized protons in FCC, then it would need a serious effort to demonstrate feasibility (at first sight, it looks extremely difficult, maybe impossible).
 - At the very least, a new level of complexity.
- Substantial modifications to injectors will be necessary
 - Long programme of staged implementation
 - Polarized protons for EDM experiments probably possible with Linac4/PS Booster (but not deuterons). No obvious synergy with FCC.
- Substantial additions to present basic FCC-hh design will be necessary. Experience shows that implementation of polarized beams as an upgrade never happens so they must be incorporated into the design from the beginning.

BACKUP SLIDES

History

- Courant, Ruth, Montague, JMJ et al discussions in early 1980s
- Montague Phys Rept
- Bell et al estimate of 12 GeV polp in PS in 1970s
- Never tried at CERN
- Have to treat all machines in FCC injector chain
- Polarization must be incorporated in machine design from the beginning, significant impact, never works as later add-on!
- Considered in past for HERA-p ring, SSC, VLHC, ...
- Polarized protons now much better understood and demonstrated – spectacular success at RHIC